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CONTENTS

A Further Analysis of Reasoning in Rats

II. The Integration of Four Separate Experiences in Problem Solving

III. The Influence of Cortical Injuries on the Process of "Direction"

BY

NORMAN R. F. MAIER

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A FURTHER ANALYSIS OF REASONING IN RATS

II. The Integration of Four Separate Experiences in Problem Solving[1]

NORMAN R. F. MAIER

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CONTENTS

INTRODUCTION

In previous studies on reasoning we have been concerned with a demonstration of the ability of rats to *integrate* or reorganize separate past experiences (Maier, 1929); the differentiation

1

between reasoning and learning (Maier, 1931, 1932a); the effects of cortical extirpation on reasoning (Maier, 1932a, 1932c); the influence of age on reasoning (Maier, 1932b); the influence of certain spatial relationships of the separate experiences on their reorganization (Maier, 1932d, and Honzik and Tolman, 1936); and the influence of confusion between separate experiences on the process of integration and reorganization (Maier and Curtis, 1937). We wish now to further analyze this process of reorganization in experience and have raised the following questions:

1. Are rats limited to the reorganization of two isolated experiences or are they capable of integrating and reorganizing as many as four experiences?

2. Will the necessity of reorganizing four experiences greatly increase the problem's difficulty?

3. To what extent do previous solutions or integrations interfere with later integrations?

4. How does the integration of the separate experiences proceed?

5. Do all rats approach difficult problems in the same manner?

6. Finally, is there any meaning to the activity or lack of activity shown by animals when first confronted with a problem?

It is the purpose of this investigation to answer these questions at least in part. We have therefore utilized a somewhat more involved situation in that four separate experiences had to be integrated before the reward could be attained. This increase in the number of experiences required for integration allowed for a greater analysis of errors and made possible the observation of more details than was possible in the problems previously utilized.

<center>METHOD AND PROCEDURE</center>

The apparatus used is shown in figure 1. The two large tables, A and B, have a number of opaque (wooden) screens (10 inches high) erected on their tops so as to obstruct the view from one part of the table to the other. Pathways (2 inches wide) form bridges between the tables. The broken lines represent sections of pathways which may be removed. Screens at the ends of the tables make these invisible from the tables. Table A also con-

tains a wire obstruction which separates point F from the rest of the table. If the removable sections of pathway are in place, there is a continuous indirect route from point S to F by way of the tables and pathways. By having food placed at F and the rat
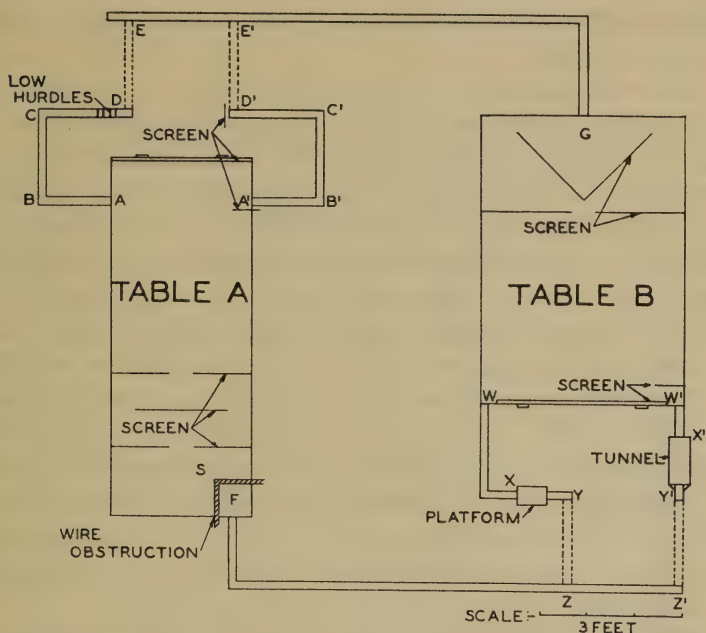
FIG. 1. DIAGRAM OF APPARATUS USED FOR TESTING THE ABILITY OF RATS TO INTEGRATE 4 SEPARATE EXPERIENCES

The tables and pathways form a continuous indirect route from the starting point (S) to the food-place (F). The two pairs of broken lines (DE, D'E', and YZ, Y'Z') indicate sections of interchangeable pathways. Since but one member of each pair of the interchangeable paths was in place on each test the route to food could be varied from day to day. Screens obstructed the vision so that the pathway in place could not be seen until after a choice had been made. The route to food on each day could be determined only from the specific part experiences given immediately before the test. Characteristic land marks making for visual, tactual, and kinesthetic sensory differences are present to reduce confusion.

placed at S, one can present the rat with a problem which requires it to take a roundabout path to food with choice-points at A, A', and W, W'. Any one of the two alternatives at the two choice-points may be passable depending on which section of bridge is in place.

The problem is so arranged that the correct route to food may be constructed by the proper integration of the pertinent past experiences. The various past experiences are given to the rat in the following manner.

1. Sections DE and D'E' are removed and the rat is permitted to explore table A and paths A to D and A' to D' for 10 minutes per day for 6 days.

2. Following each day's exploration of table A, a similar period of exploration is given on table B. Sections YZ and Y'Z' are now removed, so that the exploration includes table B with paths extending to E, Y, and Y'. The pathways and the arrangements of the screens are unique for each table in order to reduce the possibility of confusion between different parts of the apparatus.

After the rats have had more than ample exploration of the above two unique situations (each giving them an isolated set of experiences), they are given two additional experiences as follows:

3. An interchangeable section of pathways is put in place at either DE or D'E'. A rat is then placed at D or D' (depending on which bridge has been put in place) and allowed to cross to E or E' and hence to G. At point G it is picked up before it passes around the "V"-shaped screen. (It should be noted that point D is unique in that sections of wood $\frac{3}{4}$ inch high are placed at this point and point D' has a section of screen next to it.)

4. After the rat is removed from G it is carried to point Y or Y' and section YZ or Y'Z' is in place. It is now permitted to pass from this point to F at which point it finds food. In carrying the rat to Y or Y' the experimenter uses different routes so that the method of carrying will not serve as a cue.

Traversing the two bridged sections of pathways and continuing to the other table constitute two additional past experiences. Each of these experiences is given to the rat three times in order to insure the learning of the sections of pathways. Care is always taken not to permit the rat to proceed backward. Thus if placed at D, the rat was not permitted to go to C.

On the day of the test each rat thus has had the following four separate experiences: (1) exploration of table A to points D and D'; (2) exploration of table B to points Y, Y', and E; (3) running

a pathway from D (or D′) to G; and (4) running a pathway from
Y (or Y′) to F.   With food at point F, the rat was then placed
at S for the test.   To reach food it was necessary for the rat to
leave table A by means of the path which led to the section of
bridge in place.   (Since a screen was present at the end of the
table it was impossible for the rat to see the section of bridge
which was in place until after it had left the table.)   The choice

TABLE 1

The Combination of Bridges Used on Each of the Twenty Tests

TEST	SECTION OF BRIDGE IN PLACE AT FIRST CHOICE-POINT	SECTION OF BRIDGE IN PLACE AT SECOND CHOICE-POINT	CHANGES IN BRIDGES FROM PREVIOUS DAY
1	DE	YZ	
2	D′E′	Y′Z′	Both
3	D′E′	YZ	Second
4	DE	Y′Z′	Both
5	DE	YZ	Second
6	D′E′	YZ	First
7	DE	Y′Z′	Both
8	D′E′	Y′Z′	First
9	D′E′	YZ	Second
10	DE	Y′Z′	Both
11	DE	YZ	Second
12	D′E′	Y′Z′	Both
13	DE	Y′Z′	First
14	DE	YZ	Second
15	D′E′	Y′Z′	Both
16	D′E′	YZ	Second
17	DE	YZ	First
18	D′E′	Y′Z′	Both
19	D′E′	YZ	Second
20	DE	Y′Z′	Both

was regarded as an error if the rat actually entered the path
(A or A′) which did not lead to the bridge.   If the rat chose
incorrectly it was not removed but was permitted to return to the
table and take the alternative route.   On table B a similar choice
was presented so that the animal could leave the table at point
W or W′.   (The screen at the end of this table prevented the
animal from seeing the bridged pathway until after a choice had
been made.)

On the following day a similar test problem was presented. Again four experiences were given, but a different combination of the bridges was used. A total of 20 tests was given to each rat on separate days. Since four different combinations of bridges were possible, each combination was presented to the animal on five occasions. The problem for the rat was always the construction of a route to food from the exploratory experiences given on that day. Since tables A and B were explored each day with all bridges removed, the rats had an opportunity to learn that the route of the previous day no longer led to food.

The test combinations used are shown in Table 1. It will be seen that changes from one day to the next, were made in both bridges on 8 occasions; the first bridge only (DE or D'E') was changed on 4 occasions, and the second (YZ or Y'Z'), on 7 occasions. The first bridge was therefore changed on a total of twelve occasions, the second on 15 occasions. Rats choosing on the bases of the run made on the day before would, therefore, make less than a chance score at each bridge. Since each section of bridge was in the same place on ten of the 20 tests any animals developing position habits would, therefore, make a chance score at each of the choice-points.

DESCRIPTION OF SUBJECTS

In the first part of this study 56 male and female albino and pigmented rats were used. Since it was found that sex and pigmentation were unimportant determinants of the score made on reasoning tests (Maier, 1932c) no separate treatment of data was made with regard to such individual differences.

The previous experience of the animals consisted of 20 days of testing on the simple reasoning problem (Test R, Maier, 1932a) which required the reorganization of two separate experiences.

The rats ranged from 9 to 18 months in age and most of them were over a year old. Additional rats were used to make further analyses of behavior. In their case age and past experience were sometimes different from that described above and when their scores are treated these variations will be indicated.

RESULTS.   I. ANALYSIS OF SCORES

(a) *Preliminary Analysis*

When first presented with the test situation some rats failed to leave the starting table A.   There was considerable back and forth running at first but this activity gradually subsided.   When activity ceased for several minutes, the animals were pushed toward a choice-point and thus were caused to run.   This assistance was only necessary in some cases and was never necessary after the animal had reached table B.   After one or two runs with the above described assistance these animals ran as actively in the situation as those not requiring help.   Trials in which assistance was given were regarded as preliminary and scores presented in this study are based entirely upon unassisted performance.

Later in the paper we wish to present a more detailed analysis of this preliminary behavior, but for the present we are concerned with the accuracy with which the animals perform after they reach the point of making choices in this situation.   The accuracy of such choices is, of course, quite independent of any assistance given in teaching them to make a choice.   Also, as indicated above, many rats required no assistance.

In each case the rat was allowed to make 2 or more trips to the food so that an errorless run was experienced on each day.   These additional runs are not treated in our data because, in such cases, the previous run may determine the choice and reduce them to a learning problem.

In Table 2 the scores for the individual rats are given.   The second column shows the number of correct responses at the first choice-point in a total of 20 trials.   Since 2 alternatives were present, a score of 10 might be expected on the basis of pure chance performance.   A position habit would also result in 10 correct responses since each alternative was correct in 10 of the 20 trials.   Reactions determined by the correct choice of the day before would result in less than 10 correct choices at this choice-point since the first bridge was changed on 12 occasions.   Scores

TABLE 2

Scores Made by Rats on Complex Reasoning Problem

RAT	FIRST CHOICE-POINT CORRECT IN 20 TRIALS	SECOND CHOICE POINT CORRECT IN 20 TRIALS	PERFECT RUNS CORRECT IN 20 TRIALS
1M	14	18	14
2M	14	20	14
3M	8	18	8
4M	12	18	12
5M	10	20	10
6F	12	16	10
7F	12	12	8
8F	12	14	10
9F	14	18	14
10F	8	16	8
11F	16	16	14
12F	16	14	13
13F	12	16	8
14F	15	13	12
15F	12	14	10
16M	7	18	7
17M	16	17	13
18M	15	19	15
19M	13	20	13
20M	13	17	10
21M	11	12	10
22M	10	19	10
23M	10	12	9
24F	15	16	14
25M	13	12	11
26M	12	18	12
27M	17	18	15
28M	8	19	8
29M	13	14	10
30M	10	15	9
31M	12	15	10
32M	10	15	9
33M	10	17	10
34M	12	16	10
35M	14	17	12
36M	16	17	13
37M	16	17	14
38M	14	12	8
39M	13	17	12
40M	15	17	13
41M	14	16	11
42M	10	19	9

TABLE 2—*Concluded*

RAT	FIRST CHOICE-POINT CORRECT IN 20 TRIALS	SECOND CHOICE-POINT CORRECT IN 20 TRIALS	PERFECT RUNS CORRECT IN 20 TRIALS
43M	11	20	11
44M	17	17	14
45M	14	16	11
46F	18	12	12
47F	15	13	13
48F	13	16	12
49F	13	13	9
50F	15	15	13
51F	15	13	11
52F	12	10	7
53M	9	11	8
54M	12	11	10
55M	12	14	11
56M	14	14	12
Average.............	12.79	15.70	11.00
Percent Correct.....	64.0	78.5	55.0
S.D.................	2.48	2.63	2.09
P.E. dist...........	1.67	1.77	1.41
P.E. m.............	.22	.24	.19

greater than 10 would either indicate reactions based upon the integration of the separately given previous experiences or good luck. It remains for the statistical analysis to exclude the latter factor.

It will be seen that the average score on this first choice is 12.79 ±.22 correct in 20 trials (64.0 percent). Inspection of the individual scores shows that 44 of the 56 rats made more than 10 correct responses and many of these individual scores were decidedly above chance expectations.

A similar analysis holds for the responses made at the second choice-point. A score of 10 could be achieved by chance and a score less than this would result if the choice were determined by the previous day's run since this choice-point was changed on 15 occasions. Column 3 gives the individual scores made at the second choice-point. It will be seen that the average rat made 15.7 ±.24 correct responses in 20 trials (78.5 percent). All but one of the rats made scores better than 10 correct.

Thus at both choice-points the animals, as a group, make scores which show the effective utilization of the previously given separate experiences. Of interest is the fact that the score at the second choice-point is considerably better than that made at the first choice-point. It seemed that the difference in performance might be due to the fact that each animal is previously shown the second bridge in connection with food, and so reacts more definitely to it than to the bridge at the first choice-point. Eight rats were therefore given no food in connection with experiencing the bridge at the second choice-point. The average score at the first choice-point was 13.0 correct (65.0 percent), and at the second choice-point, 15.75 correct (78.8 percent). Under the usual testing conditions, these same animals made scores of 71.3 and 76.3 percent correct at the first and second choice-points, respectively. The slight difference in score under these two testing conditions is therefore in the wrong direction to make the food association a possible explanation of the difference in score at the two choice-points. Two other rats were given food in connection with experiencing the bridge at the first choice-point as well as at the second. This modification also failed to change the trend in scores. It seems then that we must seek elsewhere for an explanation of this difference in score. For the present we can regard it as a condition which is not produced by the procedure and continue with an analysis of the scores made on the problem as a whole.

On the basis of chance the animal should choose correctly at both choice-points in 5 out of 20 trials. Column 4 shows the average to be 11.0 or 55.0 percent correct. This score is definitely above chance expectation.

It is, however, possible for an animal to make a score of 10 by reacting to only part of the problem. Thus it might reduce the present problem to a simple reasoning problem by making a chance score at the first choice and reacting only to the previous experience of running over the second bridge; thus completely failing to react to the problem as a whole. Before we can credit an animal with solving the whole problem we must demand that it make more than 10 correct responses at each of the two choice

points as well as more than 5 runs which are correct at both choice-points. If we impose this criterion, we find that 43 of the 56 rats (76.8 percent) surpassed it.

Thus, with decidedly more than half of the animals making a score greater than chance on the basis of this criterion, it seems that we must not only grant that many rats utilize some of the previously given experiences, but that they utilize all of them in solving the problem.

Perhaps more important than demonstrating the success of rats in integrating 4 separate experiences, is the analysis of individual differences and other factors which influence the score.

(b) Individuals Grouped According to Types of Reactions at the Two Choice-Points

A close examination of Table 2 shows that the rats fall into 3 groups with respect to the type of score made. Thus, some rats made better scores at the first choice-point than at the second; others made better scores at the second-choice point than at the first; and still others made approximately equal scores on the two parts. Hereafter we will refer to these groups as A, B, and C, respectively. It will be of interest to study these differences in score between these groups of rats to determine whether they employ different techniques.

In Table 3 the scores made by each of the three groups are separately analyzed.

The first column gives the number of rats in each group and the second and third columns give the average scores and probable errors of each group at the first and second choice-points, respectively. The last three columns give the scores made on the problem as a whole, showing the number of perfect runs, the number of runs containing an error at one choice-point, and the number of runs in which errors were made at both choice-points.

That the scores of each of these groups of rats is distinctly different at the two choice-points is shown by Table 4 in which the critical ratios are given. This ratio is greater than 3 in all cases except one. Groups A and C make similar scores at the

first choice-point but on the second choice-point their behavior is reliably different.

TABLE 3

Animals Grouped According to Type of Score Achieved

GROUP	NUMBER OF RATS	AVERAGE NUMBER OF CORRECT RESPONSES AT FIRST CHOICE-POINT	AVERAGE NUMBER OF CORRECT RESPONSES AT SECOND CHOICE-POINT	AVERAGE NUMBER OF TRIALS IN WHICH		
				Both choices were correct	One choice was correct	Both choices were incorrect
A. Rats which made a better score at the first choice-point than at the second	7	15.00±.43 (75.0%)	12.40±.30 (62.0%)	10.86±.58 (54.3%)	5.86±.56 (29.3%)	3.29±.52 (16.5%)
B. Rats which made a better score at the second choice-point than at the first	34	11.56±.24 (57.8%)	16.80±.25 (84.0%)	10.47±.19 (52.4%)	7.38±.25 (36.9%)	2.15±.23 (10.8%)
C. Rats which made similar scores at the two choice-points (within one point of each other)	15	14.40±.41 (72.0%)	14.73±.48 (73.7%)	12.00±.53 (60.0%)	5.27±.42 (26.4%)	2.73±.53 (13.7%)

TABLE 4

Critical Ratios of Averages Between the Three Groups of Rats

	COMPARISON OF GROUP A WITH GROUP B		COMPARISON OF GROUP A WITH GROUP C		COMPARISON OF GROUP B WITH GROUP C	
	Choice-point					
	First	Second	First	Second	First	Second
Difference between means..............	3.44	4.37	.60	2.30	2.84	2.07
Probable error of difference............	.49	.85	.59	.57	.48	.54
Critical ratio.........................	7.02	5.14	1.02	4.04	5.92	3.83

Since the rats may be divided into three groups according to the way they react to the two choice-points, it is important to

determine whether these individual differences are produced by the problem situation or whether they are the result of differences in preferences for characteristic parts of the situation. For example, certain animals spent considerable time in the tunnel during their exploration period. Such a preference might result in a chance score being made in the second choice-point and thus cause the first choice-point to appear to be the important part to which the rat reacted. It is therefore necessary to eliminate any differences in reactions which might pertain to our specific apparatus before we can assume that the serial position of the choice-points is a determining factor.

To solve this aspect of the problem we tested twelve rats on each half of the problem. The test of the first choice-point consisted of having the animal run across the bridge in place (DE or D'E') and proceed to point G on table B where it found food. After three runs to the food at G, it was placed at S. The reactions to the second choice-point were tested by permitting the animal to make three trips across the bridge (YZ or Y'Z') to F for food and then testing the animal by starting it at G. Each animal was given ten tests on each half of the problem; six animals running the second half first and the other six running the first half first. One test was given daily.

The average score at the first and second choice-points under these conditions of testing was found to be the same, being 73.3 percent correct. These same animals previously had made 67.9 percent correct responses at the first choice-point and 59.6 percent correct reactions to the second when they were solving the problem as a whole. More important, however, is the average deviation in score between the two choice-points. When the problem was presented as a whole, the average deviation was 2.83, but when presented in halves, it was only 1.67. It seems that the choice-points themselves differ slightly in the reactions they produce, and each animal makes a similar score on each part. When the two parts are presented as parts of a single problem, they immediately have different influences. Not one of the 12 animals made identical scores at the two choice-points when the choice-points were part of the whole problem, but five

made identical scores at the two choice-points when these were presented as separate problems.

From the above analysis it seems that the individual difference we have found to be present must be regarded as differences in approaches to a complex problem and cannot be regarded as artifacts produced by our specific apparatus.

From Table 3 it will be seen that most of the animals (Group B) reacted more accurately at the second choice-point than at the first, and it is these individuals which make the accuracy of responses for the total group (see Table 2) higher at the second than the first choice-point. Of the 34 rats in this group 12 made scores of ten or less at the first choice-point and may therefore be suspected of reacting to part of the problem only. If these animals merely react to the second half of the problem situation and make their first choice purely by chance, we might expect them, on the part to which they react exclusively, to make a higher score than the other animals in their group. However, their average score on the second half is only 83.0 percent correct, which is no better than the score of 84.6 percent made by the other 22 animals of this group which made better than a chance score at the first choice-point.

The technique of reacting exclusively to part of the situation therefore seems not to be a successful method, and it is possible that it is resorted to by inferior animals. This possibility is supported by the following facts: the above 12 animals made an error at one choice-point in 40.9 percent of the twenty runs, and made errors at both choice-points in 15.5 percent of the twenty runs; whereas the other 22 animals of this group made an error at one choice-point in 34.8 percent of the 20 trials and two errors in 8.2 percent of the trials. The rats which reacted most definitely to part of the problem, are on the average, responsible for nearly twice as many of the runs which were completely wrong as the other animals in this group. Reacting to part of the problem situation seems, therefore, to be a characteristic reaction of inferior individuals rather than a general method of making a good score without reacting to the total problem. The inferiority of these animals was not apparent in the simple reasoning test in

which their average score was equal to that of the remainder of the group.

If we now return to Table 3 we find that the rats which performed best at the first choice-point (Group A) did not do so to as great an extent as the animals which performed best in the second choice-point (Group B). As a consequence, the difference in scores between the nonpreferred and the preferred choice-points is not as great for Group A as it is for Group B (a difference of 13.0 percent for Group A as against 26.2 percent for Group B), nevertheless the total performance of Group A is slightly better than that of Group B.

Group C which consists of the animals which react to both choice-points to about the same degree, made a score on each choice-point which is decidedly higher than that made by either group on their nonfavored choice-points, and which is somewhat lower than that made by the other two groups on their favored choice-points. The total effect of the performance of Group C was to cause them to make a slightly greater number of completely correct runs than either of the other groups (60.0 percent as compared with 54.3 and 52.4 percent perfect runs). It therefore seems that animals which react to the total situation have a slight advantage over the other animals.

(c) Effect of One Day's Problem on the Next for Each of the Three Groups of Rats

We have already seen that an animal cannot profit by reacting to what it has learned on the run made on the preceding day (i.e., it cannot exceed chance performance). It is, however, possible that this previous day's run may have an adverse influence and so increase the errors. If the previous day's behavior has an influence, it may vary from animal to animal and with the difference in problems presented on successive days.

For an examination of the combination of paths used from day to day it is necessary to again refer to Table 1. On 4 occasions (trips 6, 8, 13, and 17) the combination differed from that used on the preceding day because of a change in the first bridge only (DE changed to D'E' or vice versa). On 7 occasions (trips 3, 5,

9, 11, 14, 16, and 19) the second bridge only was changed (YZ to Y'Z' or vice versa) and on 8 occasions both bridges were changed from the arrangement of the day before (trips 2, 4, 7, 10, 12, 15, 18, and 20).

Since each rat explored each part of the situation with both bridges removed before the test of the day, the rat had an opportunity of removing the tendency to run to the previous day's bridge, but this does not mean that all effects of the previous day's test run have been eliminated.

Since we have already seen that the animals could be divided into 3 groups according to their success on the two choice-points, we have analyzed the effects of the changes in the bridges on these 3 groups.

Table 5 summarizes the results of this analysis. From this table we can see the effect of a change in the first bridge only (DE or D'E'), a change in the second bridge only (YZ or Y'Z'), and a change in both bridges, for each of the 3 groups of rats. The scores made after these different types of changes in the bridges are given in terms of the percent of correct responses made at each choice-point; the percent of completely correct runs; the percent of runs in which errors were made at one choice-point; and the percent of runs in which errors were made at both choice-points. For example, the 7 rats of Group A were confronted with 23 runs in which the arrangement of the first bridge was different from that of the day before. Their responses at the first choice-point were 82.6 percent correct and at the second choice-point, 69.6 percent correct. Completely perfect runs were made on 65.2 percent of their 20 runs; one error was made on 26.1 percent of the runs; and errors at both choice-points were made on 8.7 percent of the runs.

Inspection of this table shows that the responses of the 3 groups of rats are quite different when confronted with similar test situations.

With respect to exchanging the bridge at the first choice-point we may point out the following differences between the groups:

1. The animals which made their best score at the first choice-point (Group A) adapted the best to the change and made the

highest score at this choice-point; the animals which made their best score at the second choice-point (Group B) adapted most poorly to the above change by making the lowest score at the first choice-point; and the animals which reacted equally well to both choice-points (Group C) made a score at the first choice-point which is about half way between that of the other two

TABLE 5

The Influence of a Change in the Problem on Accuracy in Performance

GROUP	NUM- BER OF RATS	PART CHANGED	NUM- BER OF CASES*	SCORE PERCENT CORRECT CHOICES				
				First choice-point	Second choice-point	Both choice-points		
						0 error	1 error	2 errors
A. Score better on 1st choice-point than on 2nd	7	1st	23	82.6	69.6	65.2	26.1	8.7
		2nd	48	79.2	89.6	75.0	23.9	1.1
		Both	51	64.8	29.4	27.5	27.5	33.3
B. Score better on 2nd choice-point than on 1st	34	1st	114	47.4	93.0	46.5	47.4	6.1
		2nd	215	80.0	92.6	75.3	22.8	1.9
		Both	236	41.1	69.9	33.9	43.6	22.5
C. Score nearly equal on the two choice-points (within one point)	15	1st	55	63.6	83.6	54.5	38.2	7.3
		2nd	101	94.1	88.1	84.1	14.8	1.0
		Both	111	57.6	56.7	37.8	35.1	27.1
Average....................		1st		64.5	82.1	55.4	37.2	7.4
		2nd		84.4	90.1	78.1	20.5	1.3
		Both		54.5	52.0	33.1	39.3	27.6

* On a few occasions a rat did not run on a particular day, and since these failures to make a choice were not recorded as runs, the number of cases is less than the product of the number of changes of a particular kind and the number of rats. This column gives the total number of times a particular kind of change was presented to a rat.

groups. Thus, Group A made a score of 82.6 percent correct at the first choice-point; Group B, a score of 47.4 percent (slightly below chance); and Group C, a score of 63.6 percent. The average for the 3 groups is 64.5 percent correct.

2. The behavior of the 3 groups in regard to the second choice-point is also different. Group A made a poorer score at this unchanged choice-point than at the changed one, whereas Groups

B and C made better scores at the second choice-point. Again the score of Group C falls about midway between the scores made by Groups A and B. The percent of correct responses at the second choice-point for Groups A, B and C are 69.6, 93.0 and 83.6 percent, respectively.

3. The total effect of the above change was to cause Group A to make 65.2 percent perfect runs; Group B, 46.5 percent perfect runs (a score considerably lower than that of Group A); and Group C, 54.5 percent perfect runs (a score which again is about midway between that of the other two groups).

Thus, when the first bridge is changed, the behavior of the rats which make the better scores on the first choice-point show trends exactly opposite to that of rats which react better at the second choice-point. This seems to show that these groups of animals are reacting quite definitely to different aspects of the situation. Although most of the rats in Groups A and B are solving the problem as a whole, the different parts of the problem have a quite different emphasis. This conclusion is further supported by rats in Group C which show a behavior effect from the change which is intermediate between that of the other two groups.

Because Group C made a better score at the unchanged choice-point than at the changed one, it seems that a change in the problem is conducive to causing errors at the point changed. This is an indication of the influence of the previous day's run on the behavior of the animals.

The effects of exchanging the bridge at the second choice-point are as follows:

1. Group A again made the better score at the changed choice-point than at the unchanged one, despite the fact that this is not its favored choice-point. In fact, its score is decidedly above chance at both choice-points and 75.0 percent of its runs are correct at both choice-points.

2. Group B made about the same score at the second choice-point when it was changed, as when it remained unchanged (92.6 and 93.0 percent, respectively), but leaving the first choice-point unchanged has raised its score from 47.4 to 80.0 percent

correct at this choice-point. The behavior of Group B is much better on the whole problem with a change at the choice-point to which it reacts most definitely (i.e., the second) than with a change at the other choice-point. Thus, the number of the correct responses at both junctions (i.e., perfect runs) is 46.5 percent when the first choice-point is changed and 75.3 percent when the second is changed.

3. Rats in Group C also suffered less from a change at the second choice-point than from a change at the first as is shown by the fact that the scores at both choice-points are high. As in the case of changes made at the first choice-point, they made the better score at the unchanged choice-point, again showing the influence of the previous day's run.

The general indication is that a change made at the second choice-point is more likely to be reacted to by all groups than a change made at the first choice-point. The average of the three groups for runs completely correct is 55.4 percent when the first part is changed and 78.1 percent when the second part is changed.

The effects of changing the bridges at both choice-points may be summarized as follows:

1. Group A shows better performance at its favored choice-point than at its unfavored choice-point, since it made a score of 64.8 percent at the first choice-point and 29.4 percent at the second.

2. Group B also shows better performance at its favored choice-point, than at its unfavored one, since it made a score of 41.1 percent at the first choice-point and 69.9 percent at the second.

3. Group C which has no definitely favored choice-point showed about the same behavior at the two choice-points in that it made a score of 57.6 percent at the first choice-point and a score of 56.7 percent at the second. This group shows the best adaptation to the double change in that it made 37.8 percent perfect runs, whereas Groups A and B made 27.5 and 33.9 percent perfect runs, respectively.

Thus Groups A and B again demonstrate their dominant reactions to part of the situation and show about equal per-

formance at their favored choice-points (scores of 64.8 and 69.9 percent, respectively), but Group B surpasses Group A in its reactions to the unfavored choice-point by making a score of 41.1 percent at the first choice-point while Group A made a score of 29.4 percent at the second choice-point. On the problem as a whole both of these groups are somewhat inferior to Group C which showed no marked dominant reactions to part of the problem and thus made scores above average at each of the choice-points as well as the greatest number of perfect runs.

For the rats taken as a whole a change at both choice-points results in approximately half as many perfect runs as the average number obtained when a change is made at one choice-point only. The percent of perfect runs after a double change is 33.1, and the average percent after the single changes is 66.8 $\left(\dfrac{55.4 + 78.1}{2} \right)$.

(d) Evidence Showing that Problem is Solved as a Whole

Changing the bridges at both choice-points lowers the scores for all three groups at the first choice-point to a greater extent than changing the first bridge alone. Thus the average score at the first choice-point is 54.5 percent when both bridges are changed, but the score at this choice-point is 64.5 percent when only the first bridge is changed. The average score for all groups at the second choice-point falls to 52.0 percent when both choice-points are changed and is 90.1 percent when only the second is changed. This means that the double change is a more difficult adjustment, not only because it affects both parts separately, but also because it introduced a further difficulty. If the double change affected only the parts changed, a single change should be as difficult an adjustment to make at the point changed as the double change, since the additional change would show its influence only at the other choice-point. However, the results clearly show that the addition of a change at the second choice-point lowers the accuracy of the performance at the first choice-point and the additional change at the first choice-point lowers the score at the second choice-point. This means that the rats are, to a great extent, solving the problem as a whole.

*(e) Evidence Showing that the Solution Pattern is Built up in the
Forward Direction*

The foregoing data also show a relative difference in difficulty
at the two choice-points. Thus, from Table 5, we see that the
average score in terms of perfect runs is 55.4 percent when the
first bridge is changed and 78.1 percent when the second bridge is
changed. This indicates that a change in the first part of the
round-about route disrupts behavior to a greater degree than a
change in the latter part of the route.

A further difference between the two parts of the round-about
route is found if we examine the increase in difficulty created when
both bridges are changed as compared to a change in one bridge
only. Thus, on the one hand, a change at both bridges results
in 54.5 percent correct responses at the first choice-point, whereas
a change in the first bridge only results in 64.5 percent correct
runs at the first choice-point. The difference in score resulting
is 10.0 percent, indicating that the addition of a change at the
second bridge is responsible for this increase in difficulty at the
first choice-point.

On the other hand, a change at both bridges results in 52.0
percent correct responses at the second choice-point, whereas a
change in the second bridge only results in 90.1 percent correct
response at the second choice-point. The difference in score
resulting in this case is 38.1 percent, indicating that the addition
of a change at the first bridge greatly increases the difficulty at
the second choice-point.

It is therefore apparent that a change in the first bridge dis-
rupts behavior at the second choice-point more than a change at
the second bridge disrupts behavior at the first.

In maze running, Borovski (1927) found that changes in the
latter half of a maze were more destructive to good performance
than changes in the first part. His and other experiments have
shown that, other things remaining equal, the maze habit is built
up in the backward order. Since changes in the first part are
more destructive to the construction of the round-about path to
food in our experiment, it seems that the solution pattern tends

to be built up from the starting place to the food place, or in other words, in the forward direction. This, of course, would not be true for rats which failed to react to the first part of the problem and solved only part of the problem.

If this difference in the order in which a maze pattern and a solution pattern in reasoning are built up is valid, it serves as a further qualitative difference between the processes of reasoning and learning. (For other differences, see Maier (1936).)

RESULTS. II. ANALYSIS OF FACTORS UPON WHICH SUCCESS DEPENDS

(a) Age and Past Experience

We have seen that the 56 rats which were older than 9 months and which had previously been tested on a simple reasoning problem each made more than the 5 perfect runs in 20 trials which would be expected on the basis of chance performance. The ability of some individuals to pass the test may be questioned, but the average of the group (55.0 percent) is sufficiently high to dispel doubt about the ability of the group as a whole.

We wish now to present data which throw light upon the factors of age and experience. It was decided to analyze the early behavior of rats in the test situation, and for this reason the procedure was modified so as not to directly influence the animal's choice or activity in any way. It was therefore decided not to push the rats or otherwise influence their behavior during the first few tests. A trial was terminated when activity ceased, and in no case was the animal removed during the first 5 minutes. The importance of the factors of age and experience suggested itself when it was found that a new group of six seven-month old rats without previous experience failed to leave the starting table after more than 20 days of testing. At the end of this period these rats were transferred to the simple reasoning problem and all made high scores. When returned to the complex test they ran actively and made completely perfect runs in 25, 45, 50, 55, 55, and 65 percent of their 20 trials. The sescores, with the one exception, are above chance and suggest that the age increase of

2 months which had occurred since the first tests were given or the experience on the simple reasoning problem had played an important part.

In Table 6, the scores of rats with different previous experiences are compared for two age groups. The section headed "food

TABLE 6

The Influence of Age and Experience on Scores

FOOD ASSOCIATION ONLY				MAZE EXPERIENCE				EXPERIENCE ON SIMPLE REASONING TEST			
Rat	Percent correct	Trial in which rat runs	First run—correct (+), wrong (−)	Rat	Percent correct	Trial in which rat runs	First run—correct (+), wrong (−)	Rat	Percent correct	Trial in which rat runs	First run—correct (+), wrong (−)
9-month old rats											
107F	Ran 4 times, 3 correct	2nd	+	113F	Ran 4 times, 1 correct	6th	−	46F	60	1st	+
108F	45	4th	+	114F	45	1st	+	47F	65	1st	+
109F	20	5th	−	115F	45	1st	+	48F	60	1st	+
110F	35	2nd	−	116F	55	2nd	−	49F	45	1st	+
14F	35	5th	−					50F	65	1st	+
111F	30	4th	−					51F	55	1st	+
								52F	35	2nd	−
112F	35	1st	−					57F	50	1st	+
								58F	Ran 8 times, 2 correct	2nd	−
								59F	Wouldn't run		
Av.*	33.3%	3.5th	17%		48.3%	1.3th	67%		54.4%	1.1th	88%
13-month old rats											
117F	Wouldn't run			121F	50	1st	+	53M	40	2nd	−
				122F	65	1st	+	54M	50	1st	+
118F	50	5th	+	123F	50	1st	+	55M	55	1st	+
119F	50	1st	+	124F	50	4th	−	56M	60	1st	+
120F	40	1st	+								
Av.	46.7%	2.3th	100%		53.8%	1.3th	75%		51.3%	1.3th	75%

* Averages do not include cases in which incomplete data were obtained.

association only" is the record of rats which were required to run on a straight pole for food for 10 days; the section headed "maze experience" is the record of rats which learned the enclosed Lashley maze; and the section headed "experience on simple

reasoning test" is the record of rats which performed for 10 days on the simple reasoning problem. The Lashley maze was introduced to determine whether or not the transfer effect from the reasoning test was of a specific nature, and the "food association" was used to control the motivation factor.

This table is admittedly very limited, but the lack of overlapping in the distributions of scores indicates important trends. In the 9-month group the rats which received the "food association" test have a range of scores definitely below that of the rats with the maze experience or the simple reasoning problem experience. Only one rat of the "food association" group made a score as high as 45 percent, and only one rat in the other two groups made a score below this. Each of the three 9-month groups, however, contains individuals which failed to run or which ran only now and then.

The importance of experience is also suggested by the data in the third column. Since the rats were removed from the test situation when they failed to run, a record was kept of the trial on which the rat first left the starting table. The average number of the trial on which the rats of the "food association" group left the starting table was 3.5, and only one of the 6 rats ran on the first trial. In the other two groups, running on the first trial was the rule rather than the exception. (The rats which did not perform regularly have not been included in these averages.) As already pointed out, the rats in the 7-month group all failed to run.

The indication is that experience in working for food is essential and the mere running over a pole for food seemed not to be the only essential feature in the transfer. In the case of 13-month old rats, however, the kind of past experience ceases to be an important variable. Only one rat refused to perform consistently, and it had the "food association" experience. All of the other rats made scores which approximate the records shown in Table 2, and nearly all ran on the first trial.

If we suppose that the round-about path to food is taken only after it has been integrated, we can readily see why animals

incapable of reorganizing past experiences will fail to run in the situation. Experience in working for food in other situations would be conducive to continued activity in the complex situation and might furnish the necessary basis for setting up the required integration.

This raises the problem of what causes the animal to run in the situation. The solution of the problem, when experienced, will, of course, cause the animal to perform, but it may also leave the starting table without the solution playing a part. It is therefore necessary to further analyze the behavior of the rats particularly on the first few occasions on which the problem was presented.

The last column of data for each group of rats shows the percent of correct responses made on the first run in which the animal left the starting table. For the 9-month groups these scores are 17, 67, and 88 percent, and for the 13-month groups they are 100, 75, and 75 percent. The 9-month group with the "food association" experience is the only group with a score which does not exceed chance. All other groups not only surpassed a chance score but showed their best performance on the first run.

This accurate performance on the first trip suggests that the solution plays an important part in causing the animals to run in the situation. (The data for rats used in Part I cannot be analyzed in this respect because records were not taken until after the animals began to perform consistently.)

It seems then that previous experience plays a part in determining the performance of rats not over 9 months of age, but the cause of the transfer can hardly be regarded as mere training to run in the situation. At 13 months of age the importance of past experience becomes highly questionable. Whether or not rats below 7 months in age can be given the necessary experience to cause them to run cannot be determined from our limited data. For the present we wish merely to emphasize the importance of controlling both age and experience in the study of complex processes and to point out that our successful rats did not fall in the questionable age range. Since the age influence

is in the direction opposite to that found in the learning studies, lack of motivation cannot be regarded as the cause of the failure in our younger animals (see Stone, 1929a and b).

(b) Analysis of Behavior During the First Few Trials

The characteristic behavior of an animal when placed in the test situation is that of very active back and forth running between the starting point and points beyond the first screen. Careful records were made of these movements for 51 rats (including the above mentioned age groups) in order to determine their significance. We may quantify this behavior by counting the number of times the animal returns to the starting point after going beyond the first screen and before it leaves table A—that is, before it actually makes a choice between pathways A and A'.

In Figure 2 we have plotted the number of return trips to S for the early trials. Separate curves have been made for (a) 21 animals which always ran in the test situation; (b) 9 animals which never ran in the test situation; and (c) 21 animals which sometimes ran. The data for the latter group of rats were divided into two parts: (1) the trials in which they ran and (2) the trials in which they did not run.

From the figure we can see that this back and forth activity fell off rather rapidly in the case of the animals which always ran, but for animals which never ran the curve is irregular, with no marked downward trend. In the case of the rats which never ran, this activity was less during the first three trials but greater after the fourth trial than that of the animals which always ran. This difference in activity suggests that the experience of the solution of the problem is a factor in this back and forth behavior. If we consider this behavior as associated with making a choice we can understand why it should be high at first and gradually decrease as the animal experiences solutions. The first time the animal is tested it must not only discover the correct round-about route, but it must discover that a round-about route exists. After the latter discovery is made, the animal must determine (from the separate parts given) which route to take. There seem, therefore, to be two aspects to the problem and one of these

aspects is eliminated as testing progresses. (Further evidence on this point will be given in the following study (Maier, 1938).) We have already seen (Table 6) that the number of correct solutions is higher on the first trial than on the following trials. Addi-
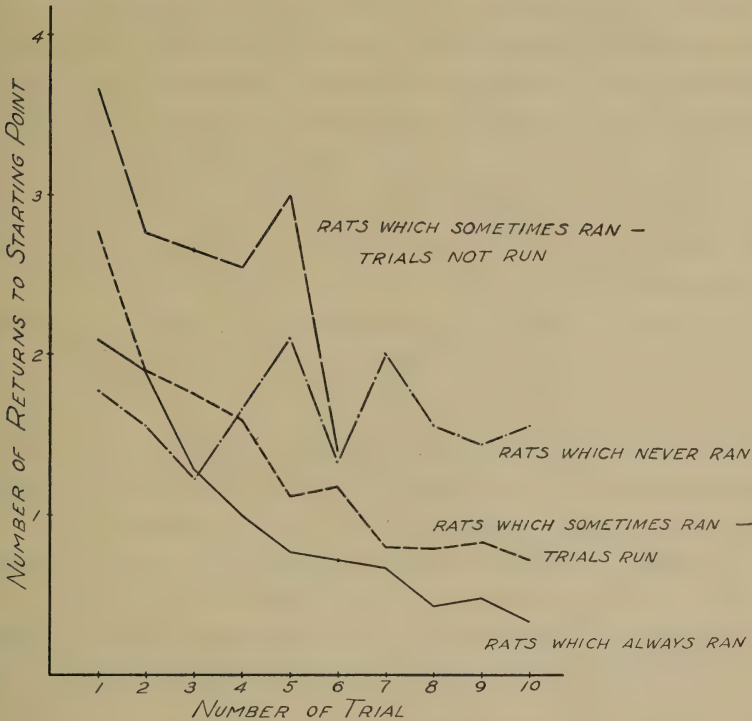
FIG. 2. CURVES SHOWING THE AMOUNT OF PRE-CHOICE ACTIVITY DURING THE EARLY TRIALS

The vertical axis shows the amount of activity in terms of the number of returns to the starting point before a choice is made. The horizontal axis gives the trial on which the activity occurred. The animals are classified as follows: (a) rats which always ran; (b) rats which never ran; (c) rats which sometimes ran, (1) trials run, (2) trials not run. Marked differences in the amount and trend of activity of these groups is shown.

tional evidence will be presented in Table 7. Because of this fact we cannot regard the later solutions as learned behavior patterns. In fact, the discovery of a round-about path introduces an interfering learning factor which may cause the animal to run without having constructed the solution. Our analysis

of the influence of one day's test on the next (see pp. 15–20) seems to bear this out. It seems then that the scores made by our rats are a measure of the ability to integrate separate experiences and this must be done on each test occasion. If an animal is capable of this integration it will discover the round-about route. The existence of round-about routes may also be discovered by accident and in this way an animal may learn to run in the situation, but in such cases the animal must make a chance score, although its activity may be great. The animals which fail to run have neither integrated the separate past experiences nor discovered by accident the existence of a route to food. For this reason they confine their activity to the starting point which is separated from the food by the wire obstruction.

The group of rats which ran part of the time (this includes rats which did not perform on the first test as well as others which ran irregularly even after the first run) shows activity trends which are similar to the other two groups. The trials in which these animals ran show activity similar to that of rats which always ran, in that there is a gradual reduction in activity. The activity differs, however, in that it is very great.

The trials on which the rats did not run show an irregular trend in activity similar to that of animals which never ran, but their activity is much greater. If we assume that this back and forth activity is due to choice behavior instigated by the problem we can understand why animals which experience the situation as a problem should show greater activity than animals which do not experience a problem. Hence it follows that the animals which run part of the time are under the tension of the problem. Since the solution terminates this activity the trials in which these animals run show fewer back and forth movements than the trials on which they do not run.

It also follows from the above assumption that animals most capable of experiencing the situation as a problem should terminate their back and forth activity sooner than those of lesser ability. We should therefore expect that the animals which always ran would be superior to those which run part of the time.

In Table 7 we have given the error score per run for the 21 rats

which ran part of the time and for the 21 rats which ran all of the time. It can be readily seen that the rats which ran on each test made the better score of the two groups with an average of 52.2 percent perfect runs as compared with 41.3 percent. It should also be noted that these rats made their best record on the first run whereas the others did not. Thus the difference in the curves of activity for these two groups (fig. 2) seems to be due to the fact that the rats which always run are superior individuals and terminate their back and forth activity because of their superior ability in reaching the solution.

Thus far we have presented evidence which suggests that the back and forth behavior is closely linked with the tensions produced by the perception of the problem. This behavior also

TABLE 7

Scores Made on Successive Test Periods

	PERCENT CORRECT RESPONSES										AVER-AGE FOR 20 RUNS
	1st run	2nd run	3rd run	4th run	5th run	6th run	7th run	8th run	9th run	10th run	
Rats which always ran..	81.0	47.6	76.2	28.6	76.2	67.1	33.3	33.3	71.4	28.6	52.2
Rats which sometimes ran..................	35.3	52.9	29.4	11.8	42.9	42.9	30.0	33.3	50.0	43.75	41.3

appears in maze running when an animal has difficult choices to make. The starting point seems to be a place for orientation. If a tension is present in our experiment, the activity should be largely between the starting point and the exit points of the table. On the other hand random activity resulting from some need should be less specific. If we therefore analyze the behavior of our different groups in terms of activity between choice-points and the starting point we should expect to find further differences between the groups. In Table 8 we have shown the number of back and forth movements between a choice-point and the starting point as well as the total number of returns to the starting point. These values are given for the first trial and for the average of the first ten trials for each of the 3 groups.

On the first test occasion it will be seen that the group of rats

which failed to run show the smallest number of contacts with choice-points, and although they show considerable activity, only 6.2 percent of their returns to the starting point are from choice-points. The groups which always ran or sometimes ran show 34.0 percent or more returns from choice-points. Rats which always ran show fewer absolute contacts with the choice-point than those which sometimes ran, but their total activity was also less. This difference in the amount of activity indicates that the former had less difficulty in leaving the starting table than the latter.

For the most successful rats the relative number of contacts with the choice-points increases (the average percent of returns

TABLE 8

Specificity of Back and Forth Activity

GROUP	NUM-BER OF RATS	FIRST TRIAL			AVERAGE FIRST TEN TRIALS		
		All returns to starting point— number per rat	Returns from choice-point— number per rat	Percent returns from choice-point	All returns to starting point— number per rat	Returns from choice-point— number per rat	Percent returns from choice-point
Rats which always ran......	21	2.09	.71	34.0	.97	.44	45.8
Rats which never ran........	9	1.78	.11	6.2	1.62	.52	32.0
Rats which sometimes ran ..	21	3.86	1.38	35.8	2.04	.71	34.8

from choice-points rises to 45.8 percent) despite the fact that their total activity decreases. Thus their behavior becomes more specific as testing continues. The rats which sometimes ran do not increase the degree of specificity. The rats which never ran also increase the specificity of their back and forth behavior indicating that repeated testing is bringing them closer to the behavior of animals which sometimes ran in the situation.

The degree of specificity of the activity on the starting table may also be measured by the time elapsing before an animal reaches a choice-point. These records are shown in Table 9. Since some of the animals were removed from the test situation at the end of five minutes, the maximum time recorded in this table is 300 seconds. Trials in which a choice-point was not reached in 300 seconds are starred. It will be seen that all rats

which always ran reached a choice-point on their first trials before the time limit had elapsed; 71.4 percent of the rats which sometimes ran reached a choice-point; and only 11.1 percent of the rats which never ran reached a choice-point in the allotted time. The average time for the first five runs of these three groups of rats is strikingly different despite the fact that the

TABLE 9

Time to Reach Choice-Point
(in seconds)

RATS WHICH ALWAYS RAN						RATS WHICH SOMETIMES RAN						RATS WHICH NEVER RAN					
Rat	1st	2nd	3rd	4th	5th	Rat	1st	2nd	3rd	4th	5th	Rat	1st	2nd	3rd	4th	5th
14F	80	55	25	40	55	12F	300	60	175	95	135	49F	300*	300*	145	90	25
24F	10	10	10	30	10	14F	215	125	190	80	65	50F	300*	30	45	165	105
46F	125	110	300*	45	35	24F	145	35	300*	75	125	51F	115	110	25	45	85
48F	60	20	20	30	40	47F	300*	300*	120	300*	300*	52F	300*	300*	300*	300*	70
49F	35	25	65	15	15	52F	30	10	15	10	5	57F	300*	300*	300*	300*	215
50F	20	10	20	15	15	53M	300*	175	45	240	285	58F	300*	300*	300*	180	175
51F	55	15	10	20	10	57F	105	90	35	300	50	59F	300*	300*	290	75	200
54F	110	35	20	300*	125	58F	55	90	300*	50	300*	78F	300*	75	300*	40	30
55F	20	25	45	125	30	78F	20	45	55	55	40	79F	300*	300*	300*	300*	185
56F	150	110	40	30	75	79F	170	130	80	300*	80						
57F	130	30	30	20	70	107F	300*	300*	300*	125	300*	Av.	279.4	223.9	222.8	166.1	121.1
112F	30	20	30	10	10	108F	150	290	35	300*	35						
114F	205	150	55	75	200	109F	135	105	35	45	135						
115F	140	50	55	45	35	110F	225	175	300*	300*	300*						
119F	70	35	15	20	10	111F	300	70	15	25	25						
120F	90	70	70	35	30	113F	300*	300*	300*	300*	300*						
121F	55	100	300*	300*	270	116F	135	130	120	125	280						
122F	170	40	220	40	10	118F	120	300*	160	80	80						
123F	185	180	20	135	200	124F	300*	65	300*	155	215						
127F	40	45	50	20	140	125F	65	40	185	15	20						
128F	30	15	50	35	20	126F	300*	300*	300*	105	300*						
Av.	86.2	54.8	69.1	66.0	66.9	Av.	189.1	149.3	160.2	146.7	160.7						

Duplicate cases in the groups are rats which were tested at different age periods. They have been *treated here as if* they were different individuals.

* Choice-point not reached at the end of 300 seconds.

arbitrary time limit favors the rats which fail to run. Rats which always ran reached a choice-point in the first five runs with times ranging from 54.8 to 86.2 seconds; those which sometimes ran had a range in times from 146.7 to 189.1 seconds; and those which never ran, a time range from 121.1 to 279.4 seconds. Only the rats which never ran showed a progressive and marked reduction in time. The other two groups began with more

specific behavior, showing that the choice-points were more
definitely reacted to at the outset.

Thus, our various methods of analyzing the presolution activity
all point to the conclusion that the experience of the solution is
the important factor which causes animals to run in the situation.
Motivation may give rise to activity, but this activity is without
specificity unless some connection between the starting point and
the food place is made. The degree of specificity in behavior
seems to depend upon the adequacy of this connection.

(c) Factors in Problem Situation which cause Back and Forth Activity

There are two possible explanations for the apparent fact that
the experience of a problem will create a tension which will
produce the back and forth behavior.

1. The food being present at the starting table will set up
vectors in the direction of the food. The round-about path when
experienced will constitute a vector in the direction opposite the
position of the food. (See Köhler, 1925; Lewin, 1935.) This
will constitute a conflict situation and account for the back and
forth activity. If one wishes to avoid the concept of vectors it
can be said that the animals have difficulty in turning their backs
on the goal, and in keeping the goal in view they return to the
starting place (see Drescher and Trendelenburg, 1927; Bierens
de Haan, 1937).

2. The choice-points are both routes to food, but only one is
functional at a time. There is a conflict between these two
alternatives particularly if previous solutions are playing a rôle
or if the solution is not clearly formulated. In this case a diffi-
cult choice presents itself and the starting point is the neutral
corner.

In order to test the foregoing hypotheses the problem situation
was altered in the following manner. Instead of the food place
being behind the wire obstruction, it was removed to a separate
small table so that pathway Z'Z (see Fig. 1) which previously
turned right to point F now turned left to a new food place. In
all other respects the situation was unaltered. When tested in

this manner the food was no longer preceptually present, rather the indirect route led to a food place which was present in memory only. If the conflict arose because of difficulty in leaving the presence of food, this change should reduce the conflict and hence the back and forth movements.

The average number of back and forth movements per trial for the first ten trials of the four rats so tested was 1.10, and 52.3 percent of these back and forth movements were returns from a choice-point. These values correspond to those made by rats which always ran in which we found an average of .97 returns per trial, 45.8 percent of which were from choice-points. Their responses were correct in 55 percent of the trials, which corresponds to that of the total group. Examinations of the records of these rats did not reveal any behavior which was different from that of rats tested in the usual manner. Since the removal of the food did not decrease the back and forth activity, there seems to be no reason to believe that this alteration of procedure was a determining factor. The back and forth activity resulting from the problem situation seems to be choice activity rather than a difficulty in leaving the starting point because of its proximity to food.

DISCUSSION OF REASONING, "UMWEG" BEHAVIOR, AND LEARNING

Two types of criticism of my experiments designed to test the integration of isolated past experiences have arisen. The one states that the behavior described is merely a case of ordinary learning; the other, that animals when tested by other experimenters fail on the problem. Both of these points are important since the one concerns a vital, theoretical issue, and the other suggests that minor differences in procedure may radically change the experimental results. It is therefore highly desirable that these points be clarified before reasoning and learning are discussed in connection with *Umweg* behavior.

In connection with the first of the above mentioned criticisms, Munn (1933) dispenses with the problem by stating that my experiments dealt with a position habit but since he does not show how the behavior can be reduced to a position habit, it is

impossible to discuss his objection. I am inclined to believe his treatment is due to a misunderstanding of some details. Wolf and Spragg (1934) have been more specific in their criticisms. They argue that because their rats improved with practice on the simple reasoning tests, learning must be the essential factor responsible for the solutions. If a change in behavior through previous repetition is their criterion for learning, we must also include fatigue, sensory adaptation, and dark adaptation under the concept of learning. Improvement in reasoning tests can arise because the elements to be reorganized have been more thoroughly learned. But this does not imply that the reorganization is the product of past experience. Wolf and Spragg do not show how the new integration can arise from past experience but regard the improvement in score as adequate evidence for learning. My own results do not show improvements in score if the separate parts of the problem are well learned and the rats are sufficiently mature. Miss Jane Loevinger of the University of Minnesota has been kind enough to show me her data from a recent experiment and her findings corroborate this point. Using the simple reasoning problem, she also found no improvement in score as testing was continued, and obtained her best records on the first day. In the present study, we find that even on the complex problems the best scores were actually made on the first test. (Other possible reasons why Wolf and Spragg were unable to reproduce our records have been presented in a separate paper (Maier, 1935).)

I do not regard Hull's (1935) analysis of my results as an attempt to reduce the phenomenon I have called reasoning to the learning process as it is ordinarily defined. Rather, he is facing the facts squarely and is complicating his S-R theory so that the phenomenon can be explained rather than denied. In accounting for the phenomenon, Hull introduces anticipatory responses and perseveration tendencies. These concepts do not appear in the earliest S-R theories, and it is for such reasons that they have been regarded as inadequate. By introducing new mechanisms into the S-R theories they can be extended to account for the so-called intelligent forms of behavior. Whether or not

any of the additional mechanisms should be called reasoning is merely a matter of taste and emphasis.

Despite Hull's addition, I am inclined not to follow him. In the first place, I am unwilling to postulate such things as perseveration, anticipatory responses, and goal gradients, which I regard as needing explanation as much as do *gestalten* and fields of strain, which he is inclined to discard. What one is willing to postulate is perhaps a matter of taste, but it seems that placing S-R units together in complex patterns is leaning over backward to save a type of theoretical analysis. Dynamic processes are not subject to such segmentation and because they are not, Hull does not regard them as useful to theory.

In the second place, I do not believe Hull can account for some of my more recent findings, particularly those presented in my study on orientation (1932d). He can extend his previous analysis to account for the present study but will have to add more units. It thus seems to me that Hull will always be in a position in which he must make his theory of intelligent behavior catch up with the newly described phenomena.

I agree thoroughly with Hull, that events must be explained in terms of antecedent events and that physical mechanisms in behavior should be constructed to meet the facts. Because I believe in physical mechanisms, I am not ready to concede that the term "reasoning" must be reserved for symbolic verbal reactions. "Symbolic behavior" is a respected concept in mentalistic psychology, but it reduces to equivalence in behavior when objectivity is demanded (see Klüver, 1933, 1936, and Maier and Schneirla, 1935). The "verbal" part of the definition merely protects man against encroachment of animals on his most cherished process.

In connection with the second criticism mentioned above, we have the study of Wentworth (1936) in which complete failure to obtain positive evidence (i.e., better than chance scores) on the simple reasoning test has been reported. I can give no satisfactory explanation of this failure to corroborate my results. To my knowledge the only difference in procedure was that water rather than food was used as an incentive. Excitement resulting

from an intense need may result in chance performance on this test but this is a question which should be answered by experiment. In contrast to Wentworth's negative results, we have studies by Wolfe and Spragg (1934), Campbell (1935), Honzik and Tolman (1936), Vaughn (1937), and Miss Jane Loevinger's study (mentioned above), in all of which scores definitely above chance were obtained.

In the problem described in the present paper, we have attempted to complicate the simple reasoning test and in so doing have made it similar in some respects to the *Umweg* experiments of Hobhouse (1901), Köhler (1925), Drescher and Trendelenburg (1927), Nellmann and Trendelenburg (1926), Bierens de Haan (1937), and others. Viewed in one way, such problems require the rat to reconstruct the route to food from separate previous experiences; viewed in another way, they require the rat to turn its back on the food and take the round-about route.

The data already presented show that when the experiment was modified so that food was not placed in view of the starting table, but on a different table, the behavior was unaltered. If the sight of food is a factor, such a change in conditions should have had a marked influence either because the change eliminated the *Umweg* aspect of the problem or because it put the food out of sight without the rat having to turn its back.

It is difficult to know whether a rat, when it runs in an *Umweg* experiment, actually runs for the food it sees behind the obstruction or whether it runs to a place which it has learned to be a food place. In either case it experiences the position of food, but in the first case turning the back is difficult because the rat must take its eyes from the food and use a substitute stimulus, such as a memory trace; whereas, in the second case this difficulty does not arise since the rat is reacting on the basis of memory traces at the outset. Is one method of behaving indicative of more intelligence than the other? Bierens de Haan (1937), for example, regards the problem as increased in complexity when the back must be turned on the goal and assumes that the animal runs to get food which it sees behind the obstruction.

Detour experiments are very useful for setting up problems for

animals. However, we must ask whether the problems thus constructed are difficult for the animal because they involve an *Umweg* or whether detour problems are difficult because they usually require the reorganization of past experiences. All problems requiring such reorganizations are not detour situations, nor do all detours require reorganization in experience. Before we can establish criteria for intelligent behavior we must, therefore, isolate the aspect of the problem which is pertinent. Detour experiments do not designate a specific process; they merely describe a situation in which behavior is blocked by an obstruction and the animal must reach the goal indirectly. When the animal succeeds on the first occasion, it is credited with "insight." This seems merely to be a name for the fact that the animal behaves in a manner similar to that of a human in the same situation. Even in studies on human beings, although the word "insight" means that certain intrinsic relationships have been experienced, we know very little about a process or function which might be expressed in objective terms. Even if it is granted, therefore, that detour experiments may demonstrate insight, we can not be sure what has been proven.

Detour experiments were first designed to test mental functions, and it is not surprising that analysis of studies of detours lead us to mentalistic rather than objective theories. At the present time, even objective psychologists use such insight experiments as intelligence tests without seeming to ask what makes them intelligence tests.

We thus have inherited the *Umweg* type of experiment and we can use it as a test of a kind of achievement without going further to determine the nature of the process upon which the achievement rests. However, one can go further, and after accepting the achievement of animals in such experiments as evidence of intelligence, attempt to discover certain common elements which characterize the *Umweg* experiment. This is Bierens de Haan's approach and he must be credited for his keen attempt to give *Umweg* experiments a reference to psychological processes.

If, instead of attempting to infer psychological processes from achievements on tests designed for other purposes, we begin with

certain notions of psychological process and create experiments to test these notions, we have a different purpose in our experimentation in that the experiments will be designed to test certain aspects of the theories. Each experiment will then have reference to a process and the achievement of the animal will be the objective measurement which is used to test the theory. The psychological process (or the behavior mechanisms) and the outward expression of the process (achievement) will thus have quite different functions in theory. The need for this distinction has been recently set forth by Werner (1937).

Because Bierens de Haan uses the achievement of an animal in the *Umweg* experiment as his criterion for intelligent behavior rather than attempts to designate a psychological process which he wishes to test, he arrives at the conclusion that the maze is an *Umweg* situation. Because food is out of sight, and most of the path cannot be seen from any one point in the maze, it becomes for him the most difficult type of *Umweg* experiment. An *Umweg* situation in which both food and pathway are always present in the visual field is the most simple test situation. This leads Bierens de Haan to believe that ability to react to memories is the characteristic feature of intelligent behavior. This amounts to reducing intelligent behavior to learning, but he does it by elevating learning to insight.

If, however, we choose the reorganization process as a pertinent psychological mechanism in higher forms of behavior, then the maze and detour experiments can be seen to make quite different demands on the animal. In the maze situation, the spatial organization can be built up by the order in which the animal is exposed to the various parts, and in this manner spatial organization is determined by the structure of the maze. In the usual type of detour experiments, however, the organization must be constructed from devious past experience. The animal must make order when no particular order existed previously. The combination of behavior segments resulting in such cases cannot be deduced from the usual laws of learning but require additional behavior principles.

Although an animal might use abilities similar to those used

in detour experiments when it runs a maze, it does not follow that it does use them. As a consequence maze behavior patterns which are built up by contiguity (i.e., in which the order is determined by factors extrinsic to the animal) cannot be distinguished from behavior patterns which are built up spontaneously, on a basis which is principally intrinsic to the animal.

I do not wish to imply that reasoning defined as the ability to "integrate isolated experiences so as to reach a goal" is a complete description of a process. The definition does, however, designate a process rather than a kind of apparatus and makes possible a distinction between the reasoning and the learning processes. Not to allow for such a distinction is to ignore differences and to imply that similarities alone are adequate for the formulation of psychological principles. As a criterion for a process, it is just as explicit as the statement of the association process.

After we have adequately delimited a given process, we can begin to study the process under various sets of conditions and to formulate laws. This has been the purpose in our present investigation.

SUMMARY AND CONCLUSIONS

A problem was constructed which was designed to test and to analyze the ability of rats to integrate four separate experiences. The apparatus consisted of two large tables and alternate paths which joined the tables. Animals explored each table separately. On different occasions they learned a route from a point on the first table to a point on the second table and also a route from a point on the second table to a fenced off portion of the first table. Thus they learned four separate segments of a round-about route to food, the starting point of which was near a wire obstruction built upon the starting table and the end of which was a food place behind the obstruction. Since the paths joining the tables could be varied, errors were possible. The apparatus permitted four possible routes to food, one of which was open on any particular test. On each test the rat was required to reach the food behind the obstruction and the correct route for any day required the reorganization of the four experiences to which the animal

had been subjected on that day. Twenty tests were given on separate days and the score is expressed in terms of the number of correct runs made. For further analysis partially correct and totally incorrect responses are also studied. A total of 107 male and female adult rats were used in the investigation, 56 of which were used for the first part of the study and 51 for the second part. The analysis of the data seems to justify the following conclusions:

1. The group of 56 normal adult rats made a score definitely above chance expectation. They made 55.0 percent completely correct responses when chance expectation would be 25 percent. The response at each of two choice-points was also definitely above chance. No rat made a purely chance record, but 23.2 percent of the cases made chance scores on part of the problem.

2. The group as a whole showed better performance on the latter part of the problem than on the first. Control experiments excluded the possibility that this difference was dependent upon different degrees of motivation or differences in preferences arising from the specific construction of the apparatus. Rather, the difference on the two halves of the problem was found to be due to the intrinsic nature of the problem itself.

3. Although the group as a whole made better scores on the latter, rather than the first half of the problem, it does not follow that this characterized the behavior of each individual. Examination of the records revealed that the individuals could be classified into the three following groups according to their types of performance: (a) those which showed better performance on the first half of the problem than on the second; (b) those which showed better performance on the second half than on the first; (c) those which showed approximately the same performance on the two halves. These differences in score seem to designate individual differences in approaches to the same problem. In a few cases, animals in the first two groups attacked the problem by merely reacting to part of the total situation. These seemed to be inferior individuals.

4. The previous day's performance had a marked detrimental effect on the problem of any given day since the retention of the

previous day's behavior was in opposition to a new reconstruction demanded by the test.

5. Analysis of the previous day's effect on the three groups of animals using different types of responses verified the contention that animals differed fundamentally in their attack on the problem. Just how detrimental the previous day's behavior was, depended upon the extent to which animals reacted to the portion of the problem in which reasoning and memory were in conflict. The parts least reacted to were most influenced by memory. Thus on some days one group of animals would be handicapped and a different group would not, and on another day the situation would be reversed. Animals which reacted most definitely to the whole situation were least influenced by interfering memories of a previous day's performance.

6. Further analysis of the nature of interfering effects of habit on the three groups revealed that in most cases the problem was reacted to as a whole.

7. This analysis also revealed that the construction of the solution pattern was in the forward direction, in contradistinction to the backward construction of a learning pattern such as the maze experiments show.

8. Records were also made of the performance of animals differing in age and previous experience on problems. Although the data are limited, the evidence indicates that the problem used in this study is beyond the scope of animals under seven months of age. Rats nine months of age have considerable success if they have had previous experience on other problems. Rats about thirteen months of age do about equally well with or without experience on other problems.

9. Detailed descriptions of the behavior of rats when first confronted with the problem reveals considerable activity which does not lead to the problem's solution. This is not random activity since it is called out by the problem. Animals which are most capable of solving the problem show this activity in a manner different from less capable animals. In the former, the activity is more specifically related to the choice-points and starting points than in the latter animals. There is evidence

that the more capable animals are under a tension which is created by the problem situation.

10. Despite the fact that this extra activity decreases as testing continues the animals show the most accurate performance on the first occasion in which a test is given. This shows that the extra activity is closely related to the problem situation.

11. The activity between choice-point and starting point was shown not to arise because of conflict between the direct and indirect route to food. Rather, any tension which is present seems to be related to a conflict between the two exits from the starting table. The starting point seems to be a point for orientation.

12. A discussion of reasoning, *Umweg* behavior and learning is incorporated to distinguish between these as well as to show that although our apparatus requires *Umweg* behavior, it is not the *Umweg* aspect as such which creates the problem.

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A FURTHER ANALYSIS OF REASONING IN RATS

III. The Influence of Cortical Injuries on the Process of "Direction"[1]

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CONTENTS

INTRODUCTION

In studies of human reasoning (Maier, 1930, 1931, 1933) we have found evidence for an integrative process which we called *direction*. This process was used to account for the selective and integrative processes involved in the reorganization of isolated experiences in such a manner that a goal is achieved. Random integrations do not overcome difficulties and solve problems. Integrations which are influenced by the end to be achieved involve a selection process, and this selection process has been

44

one of the most difficult phenomena to account for in reasoning. In our studies of human reasoning we have described the manner in which this selection process functioned. It was possible to demonstrate experimentally that a knowledge of the parts to be integrated was not sufficient to solve a problem. In such cases there was external selection, but the "set" of the organism was such as to make for a different kind of selection, and, as a consequence, the external selection (controlled by the experimenter) was of no use to the individual. When, however, the correct "set" of the organism was given by the experimenter, solutions could be caused to appear (Maier, 1930; 1931; Maier and Renninger, 1933).

The *direction* seemed to be largely dependent on the difficulty one experienced in a problem situation. Different individuals in the same problem situation therefore exhibited a variety of *directions*, and the materials selected for their attempted solutions differed widely (Maier, 1931). The general transfer effect from one problem to another was found to be one of the factors determining *direction*, and we have designated *directions* arising through this process as *habitual directions* (Maier, 1930, 1933), since they tended to lead to reproductive rather than to productive solutions. The factors which make for new directions require illucidation, but as yet we are not able to isolate them. We do know that new as well as habitual reaction tendencies arise in a problem situation. When they are adequate, the successful integrations are most likely to occur, and when inadequate it is questionable whether they occur.[2] A *direction* in thinking, when once established, tends to persist and actually blocks solutions when it is inadequate (Maier, 1933).

Our studies on rats and human beings have emphasized two aspects which are basic in reasoning.

1. The process of the reorganization of two or more isolated experiences in such a manner that the goal is achieved. This process characterizes reasoning and differentiates it from learning.

[2] A person with a wrong *direction* may even fail to recognize a completed solution when confronted with it. This phenomenon is similar to a person's failing to see a figure in a puzzle picture which may be obvious to others.

2. The process of *direction* which functions as a selection process in that it determines the nature of the reorganization. This is a dynamic process and may be present even when integrations do not occur and as such is not identical with the process of reorganization.

These aspects are not to be thought of as separate processes, but as different ways of looking at the creative process. The first emphasizes what has occurred, the second is concerned with the dynamic process which is essential to the accomplishment. Different *directions* thus may give rise to different reorganizations, and some directions may lead to no reorganization at all, since the goal fails to become part of the elements combined. From a background of past experiences, certain ones emerge to form the solution pattern. Which ones become organized into the solution pattern partly depends upon the elements of experience themselves, but as has already been pointed out, the state of the organism also plays an important part. Thus a piece of stout metal is more likely to be used as a screw-driver than is a dime, but neither or both may become used as screw-drivers depending upon factors intrinsic to the organism. It is this intrinsic function, which seems to be established in different problem situations, which we have called a *direction*. It is rather specific in nature in that it makes for specific kinds of reorganizations, but is not an element in the sense that a past experience is an element. Since it produces reorganizations in experience, it gives the elements limited and specific functions. One *direction* in thinking may thus cause a dime to be equivalent with a piece of metal, another may make the dime equivalent with two nickels and the metal a worthless scrap.

From the first aspect we know that reasoning has occurred; from the second, we know of the process. When the second is present, reorganizations may occur which may never reach a complete stage. Wrong solutions may depend upon just as good a psychological process as the correct solutions, but we can not be objectively sure that they are the same, since accidents may also make for wrong solutions. Statistically we can rule out chance factors when correct solutions are demanded.

The process of *direction* has been investigated only in human studies. For some time it has been our interest to find evidence of its presence in animals. Recently (Maier, 1937) it was suggested that Krechevsky's concept of hypothesis (see Krechevsky, 1932, 1935) might be closely allied with our concept of direction. The hypothesis behavior which an animal shows in a discrimination problem, however, would be due to habitual directions since the animal merely expresses behavior tendencies which carry over directly from its past.

In our study of the behavior of rats in a complex problem situation (Maier, 1938) we pointed out that the rat must not only discover that a round-about route to food exists, but it must also be able to construct the round-about route from past experience. The construction of the round-about route will, of course, be sufficient, but the experience that a round-about route exists might make the construction of the round-about route easier. In some cases the solution of such problems may actually pass through these two stages; in others, the solution may appear complete.

Suppose then that we give animals the experience of successfully solving problems. This will give them a certain set. When a similar problem is presented which requires a different integration, this second problem should be easier if this set is useful. As a matter of fact, more errors are made on the second test problem because of the tendency to repeat the former solution. In such cases, the learned response interferes with the reasoned response.

We may, however, avoid this influence of bad habit by utilizing a different technique. If reasoning is merely a matter of reorganization arising in the absence of directional processes, brain injuries should either interfere with the ability to reorganize or they should not. If, however, reasoning also involves what we may call *direction*, then it is conceivable that a brain injury might impair the reorganization process so that it occurs when direction is present, but does not adequately take place when direction is absent. With *direction* regarded as a process not identical with the fact of reorganization, a brain injury might

conceivably interfere with the establishment of a direction, but still allow a direction once set up to survive the operation. This would permit the same brain injuries to block reorganization in some instances and not in others.

The problem of the present investigation is to study the possible rôle played by *direction* in the problem solving of two groups of operated animals. In one group the animals will be given the necessary *direction* or set before the operation; in the second group the animals will be denied the opportunity of having a preliminary *direction*. No difference in the behavior of our groups will prove nothing, since the operation may remove the *direction* as well as the ability to integrate. A difference in our groups which is not dependent upon differences in the nature of the injuries in the groups would suggest that something survived a brain injury but could not be achieved after the brain injury had taken place.

(a) The Critical Problem

In the foregoing study we have described our method for measuring the ability of rats to integrate four separate experiences (see pp. 2–6). Each day the group of experiences differed, and food could be obtained when the separate experiences given on that particular day were properly utilized. The integration of four separate parts of pathways and tables thus constituted a round-about route to food. From previous integrations it would be impossible to go directly to food via the round-about route since it varied from day to day. For this reason, learning (i.e., the utilization of behavior sequences built up from contiguous experiences) would not only be inadequate, but, as we have found, misleading.

(b) The Control Problem

Before the animals were tested on the above mentioned complex problem, they were presented with the simple reasoning test

previously utilized (Maier, 1932). This gives us a means for comparing the effects of brain injuries on the simple and complex tests as well as for adapting the animals to routine testing before the critical tests are given.

(c) The Animals Utilized

Two groups of animals were utilized. Group I consisted of 29 male and female rats over nine months of age. This group was tested in both the complex and the simple reasoning problems before as well as after brain injuries. Group II consisted of 26 male and female rats over nine months of age. Part of the animals in Group II were tested on the simple reasoning problem before operation, but none were tested on the complex problem. All were tested on both problems after brain injury. The groups thus differ primarily in that Group I was subjected to the complex problem before brain injury whereas Group II was not. The groups are alike in that the post-operative tests were the same.

(d) Operative and Histological Method

Operations were performed under deep ether anesthesia. After trephining the skull, cortical tissue was destroyed by means of thermocautery. From 10 to 14 days were permitted for recovery. On completion of the post-operative tests, the rats were sacrificed and their brains removed. The brains were sectioned, stained with iron hematoxylin and reconstructed according to the method described by Lashley (1929). From these reconstructions, the locus and area of destruction were then determined.

RESULTS

(a) Comparison of Groups I and II

In Table 1 we have presented the records made by rats in Groups I and II after brain injury. It will be remembered that Groups I and II differ in that Group I was tested both before and after operation whereas Group II was tested only after operation. From Table 1 we see that on the simple reasoning test

the post-operative score for Group I is $18.28 \pm .25$ correct responses in 20 trials or 91.4 percent correct, whereas the score for Group II is $15.23 \pm .49$ correct responses or 76.2 percent correct. On the basis of chance we would expect an average of 10 correct responses. It is apparent that both groups as a whole surpass a chance score, although several individual cases in Group II have a pure chance record. If we demand that each rat make twice as many correct as incorrect responses before it will have satisfied our doubts as to its ability, then 8 of the 26 rats in Group II (39.8 percent) fall below this criterion, whereas 1 of the 29 rats in Group I (3.4 percent) falls below the criterion.

The groups differ even more when we compare their behavior on the complex problem. From Table 1 we see that Group I averaged $10.24 \pm .22$ completely correct responses in 20 tests (51.2 percent), whereas Group II averaged only $5.98 \pm .30$ correct responses (29.9 percent). Since there are 4 possible responses in this problem, we might expect one-fourth of the responses to be correct (25 percent) on the basis of pure chance. The record of Group II thus is hardly better than chance. The best scores, 12 and 10 correct, were made by rats 68 and 77, respectively, and these animals ran only part of the time. (See footnote of Table 1.) If we regard refusal to run on certain test trials as errors their scores become 9 and 5, respectively. Of the rats in Group I, 18 (62.1 percent) made a score of 10 or better. The complex test thus becomes a more delicate instrument for distinguishing between the groups.

Before we can assume that the difference in the previous experience of our groups is responsible for the difference in score, we must exclude all other possible differences between our groups. The first question which comes to mind concerns possible differences in the lesions suffered by the groups. Table 1 shows the average extent of brain injury for Group I to be $16.1 \pm .63$ percent and for Group II, $15.7 \pm .87$ percent. This difference in the average lesions is slight, but the distributions of the lesions are quite different. In Group I more of the lesions are near the average magnitude than in Group II. Thus the probable error of the distribution for Group I is 3.37 and for Group II, 4.38.

TABLE 1

Post-operative Scores of Rats in Groups I and II

(Scores are given in terms of the number of correct responses in 20 tests)

	GROUP I				GROUP II		
Rat	Percent destruction	Simple problem	Complex problem	Rat	Percent destruction	Simple problem	Complex problem
5M	7.4	20	14	92M	8.4	17	7
41M	10.7	20	10	90M	9.6	15	5
45M	11.7	20	12	71M	10.0	17	6
4M	11.7	18	10	98M	10.2	20	7
29M	11.7	16	9	94M	11.2	19	6
23M	11.9	20	9	67M	11.2	18	2
30M	13.1	20	11	91M	11.7	18	6
13F	13.6	19	8	97M	12.2	19	8
8F	13.7	16	10	96M	12.6	16	5
20M	13.7	20	10	66M	13.2	16	7
11F*	14.5	14	8	78F	14.8	20	6
35M	14.9	17	9	95M	15.0	13	6
19M	15.4	19	11	79F	15.5	11	3
1M	16.3	20	8	75M	17.2	16	9
42M	16.3	19	14	68M*	19.2	18	12
9F	16.5	17	10	77M*	19.2	18	10
27M	16.5	16	12	76M	20.0	16	7
44M	16.5	20	9	73M	21.0	18	6
10F	16.6	20	14	64M	22.7	18	5
40M	17.0	18	8	63M	23.3	11	5
17M	17.2	18	11	70M	23.3	8	3
2M	18.4	20	10	62M	23.4	10	8
7F	19.1	15	12	65M	24.3	16	5
33M	19.6	17	13	60M	24.9	13	4
15F	19.8	20	10	69M	28.0	8	3
16M*	21.3	19	10	61M	31.9	7	4
21M	21.7	19	8				
25M	23.0	20	8				
22M	26.8	13	9				
Mean...............	16.1	18.28	10.24		15.7	15.23	5.98
S.D................	4.99	2.0	1.81		6.49	3.62	2.20
P.E. dist..........	3.37	1.35	1.21		4.38	2.44	1.48
P.E. m............	.63	.25	.22		.87	.49	.30
Percent correct.....		91.4	51.2			76.2	29.9
Chance.............		50.0	25.0			50.0	25.0

* Cases which refused to run on several trials. Their scores for the 20 trials are based upon the proportion of correct responses in the trials in which they ran. If refusal to run is an error, these scores are too high.

In order to facilitate the comparison of scores for cases in the two groups with lesions of similar magnitude, we have made the scatter diagram shown in Figure 1.   The open circles indicate
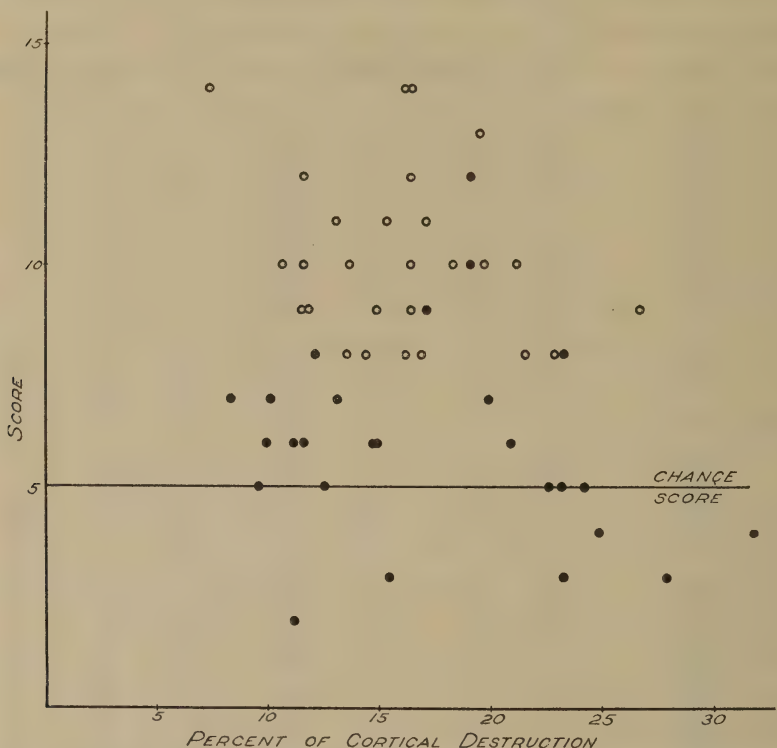

FIG. 1. SCATTER DIAGRAM SHOWING SCORE PLOTTED AGAINST MAGNITUDE OF LESION

The open circles represent rats in Group I which were given both pre- and post-operative tests; the solid circles represent rats in Group II which were tested after operation only.   Each score is given in terms of the number of perfect runs in 20 tests.   A score of 5, indicating chance expectancy, is represented by the line drawn parallel to the base.   The two solid circles representing cases with the highest scores in Group II are rats which ran only part of the time.   Their scores are calculations based upon the proportion of correct runs on the trials actually run.

cases in Group I and the solid circles indicate cases in Group II. From this diagram, one can readily see that the scores made by the two groups have very little in common.   The cases in Group II cluster close to the chance line and show a downward trend as

the lesions increase.   The scores of rats in Group II tend to be decidedly above chance throughout the range of brain injuries used.

Plates I to V show the extent, locus, and shape of the injuries. Figure 2 shows the total cortical area explored for each of the groups.   It will be seen that more of the lateral part of the brain
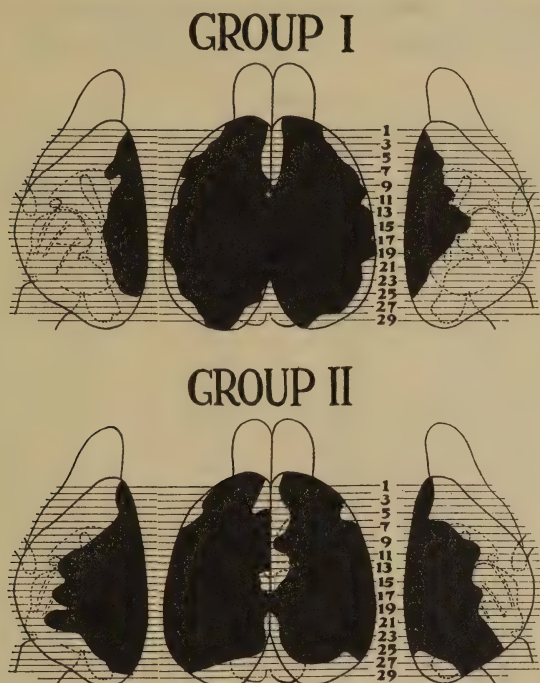

FIG. 2. COMPOSITE DIAGRAMS OF LESIONS SUFFERED BY GROUPS I AND II

These composites show that the lesions of Group II involved more of the temporal regions than did those of Group I.

has been included in the case of Group II than in Group I.   It is therefore necessary to determine whether or not the inclusion of the lateral region for some cases in Group II is responsible for the difference in score between the groups.

To test this possibility, Group II was divided into two subgroups, as follows: (a) cases whose brain injuries fell entirely within the composite lesion of rats in Group I; and (b) cases

whose brain injuries included areas outside the composite of Group I.

It was found that 11 cases had lesions which fell within the composite of Group I, and 15 cases had lesions which involved tissue beyond the composite. In Table 2 the amount of destruction and the post-operative scores are given. It will be seen that the cases which have lesions extending beyond the composite lesion of Group I make an average of 6.40 correct responses,

TABLE 2

Rats of Group II Classified according to the Locus of Injury

RATS IN GROUP II WHOSE LESIONS FALL OUTSIDE THE COMPOSITE LESION OF GROUP I			RATS IN GROUP II WHOSE LESIONS FALL WITHIN THE COMPOSITE LESION OF GROUP I		
Rat	Percent destruction	Correct responses in 20 tests	Rat	Percent destruction	Correct responses in 20 tests
92M	8.4	7	90M	9.6	5
71M	10.0	6	98M	10.2	7
66M	13.2	7	94M	11.2	6
75M	17.2	9	67M	11.2	2
68M	19.2	12	91M	11.7	6
77M	19.2	10	97M	12.2	8
76M	20.0	7	96M	12.6	5
73M	21.0	6	78F	14.8	6
63M	23.3	5	95M	15.0	6
70M	23.3	3	79F	15.5	3
62M	23.4	8	64M	22.7	5
65M	24.3	5			
60M	24.9	4			
69M	28.0	3			
61M	31.9	4			
Mean......	20.49	6.40		13.34	5.36

whereas the cases with lesions lying within the composite lesion of rats in Group I make 5.36 correct responses. Thus the difference in the locus of lesions of Groups I and II cannot explain the low score made by rats in Group II. If the locus of injury played a part at all, it was to give Group II an advantage.

This advantage is even more striking when we consider the amount of destruction. The animals in Group II which made the better scores suffered larger lesions than those making the poorer scores.

Shape of lesion has been found to be an important factor related to the extent of deterioration (Maier, 1934; Maier and

TABLE 3

The Lesion Ratios of Groups I and II

	GROUP I				GROUP II		
Rat	Lesion ratio	Scores for rats with lesion ratios 1.29 or less	Scores for rats with lesion ratios 1.30 or more	Rat	Lesion ratio	Scores for rats with lesion ratios 1.29 or less	Scores for rats with lesion ratios 1.30 or more
5M	1.35		14	92M	1.25	7	
41M	1.35		10	90M	1.45		5
45M	1.22	12		71M	3.75		6
4M	1.29	9		98M	1.20	7	
29M	1.35		9	94M	1.00	6	
23M	1.14	9		67M	1.33		2
30M	1.00	11		91M	1.15	6	
13F	1.13	8		97M	1.60		8
8F	1.31		10	96M	1.17	5	
20M	1.00	10		66M	1.78		7
11F	1.30		8	78F	1.02	6	
35M	1.68		9	95M	1.28	6	
19M	1.28	11		79F	1.28	3	
1M	1.12	8		75M	1.56		9
42M	1.21	14		68M	1.00	12	
9F	1.28	10		77M	1.59		10
27M	1.56		12	76M	1.40		7
44M	1.20	9		73M	1.58		6
10F	1.35		14	64M	1.25	5	
40M	1.27	8		63M	1.20	5	
17M	1.32		11	70M	1.03	3	
2M	1.37		10	62M	1.09	8	
7F	1.30		12	65M	1.09	5	
33M	2.00		13	60M	1.29	4	
15F	1.13	10		69M	1.14	3	
16M	1.12	10		61M	1.02	4	
21M	1.05	8					
25M	1.41		8				
22M	1.00	9					
Average...	1.28	9.75 48.8%	10.8 54.0%		1.37	5.59 28.0%	6.67 33.4%

Sabom, 1937). It is, therefore, necessary to compare Groups I and II in this regard. In the previous studies, shape was expressed as the ratio between the length and width of the lesions.

Since the direction of the longer axis was found to be unimportant, we may express these ratios by values of 1 or greater, by dividing the larger axis by the shorter one.

The results of this analysis are shown in Table 3. It will be seen that the average lesion ratio for Group I is 1.28 and that of Group II, 1.37. Since Group II tends to have a slightly greater lesion ratio and since it has been found that large lesion ratios are associated with good scores, this difference in the groups fails to account for the lowered score of Group II.

In the above table, the cases of each group are divided according to the magnitude of the lesion ratio. In both groups the better scores are associated with the larger lesion ratios, but since the range in lesion ratios is not great, the small and unreliable difference found is not surprising.

Finally, it is necessary to compare our two groups on the basis of sub-cortical destruction. Sub-cortical injuries were primarily confined to fibers of the corpus callosum and to the hippocampus. No extensive injuries were present in any case.

In Table 4 we have rated the extent of sub-cortical injuries in the anterior third, the central third, and the posterior third of the brain. A "0" indicates no injury; "1" very slight injury; "2" slight injury; and "3" considerable injury. We have also rated the cortical injury in relation to depth, since lesions did not extend through the entire thickness of the cortex in certain areas. When amount of destruction is measured in terms of area, the volume of cortex is not always the same for equal areas of destruction. We have, therefore, distinguished between lesions which are shallow in certain parts and those which are deep and thus include all of the thickness of the cortex throughout the injured surface. The former type of cortical injury is indicated by "S" (shallow) in Table 4, and the latter type as "D" (deep).

Inspection of the table shows that Groups I and II have subcortical injuries of similar magnitude. Most injuries appear in the central portion of the brain, the average rating for Group I being 1.17 and for Group II, 1.23. Comparison of cases with similar patterns of sub-cortical destruction also shows that the low scores of Group II cannot be explained by differences in subcortical injuries.

With respect to the depth of cortical injuries, Group I has relatively fewer cases with shallow injuries than Group II.

TABLE 4

Comparison of Sub-cortical Destruction in the Two Groups of Rats

	GROUP I					GROUP II			
Rat	An-terior	Cen-tral	Pos-terior	Depth of lesion	Rat	Anterior	Central	Pos-terior	Depth of lesion
5M	0	0	0	S	92M	1	0	0	D
41M	0	0	0	D	90M	0	1	0	D
45M	0	1	0	S	71M	0	0	0	D
4M	0	1	0	S	98M	0	0	0	S
29M	0	1	0	S	94M	0	0	0	S
23M	2	0	0	D	67M	0	0	0	D
30M	3	0	0	D	91M	0	0	0	S
13F	2	0	0	D	97M	0	1	0	S
8F	2	0	0	S	96M	1	0	0	S
20M	2	0	0	D	66M	0	0	0	S
11F	1	0	0	D	78F	0	2	0	S
35M	1	1	0	D	95M	0	1	0	S
19M	0	2	0	S	79F	0	1	0	S
1M	1	1	0	S	75M	0	2	0	D
42M	0	2	1	S	68M	0	3	0	D
9F	0	2	0	S	77M	0	0	0	S
27M	0	2	0	S	76M	0	1	0	D
44M	2	1	0	S	73M	0	1	0	S
10F	1	1	0	S	64M	0	2	0	S
40M	0	2	1	S	63M	0	3	1	D
17M	0	3	1	S	70M	0	3	1	D
2M	2	1	0	S	62M	0	2	1	S
7F	2	1	0	D	65M	0	2	2	S
33M	0	2	1	S	60M	0	2	0	S
15F	1	1	0	D	69M	0	3	1	S
16M	0	1	2	D	61M	0	2	1	S
21M	0	3	1	D					
25M	0	2	0	S					
22M	0	3	0	S					
Average...	.76	1.17	.24	17 S 12 D		.04	1.23	.27	17 S 9 D

Thus 17 of the 29 cases in Group I (58.6 percent) and 17 of the 26 cases in Group II (65.4 percent) had shallow injuries in certain areas. If depth of lesion is an important factor in determining

the degree of deterioration, it is not the cause of the difference in scores between our groups.

An examination of the lesions in Groups I and II thus fails to uncover any differences which might account for the difference in score between our groups.

Another possible difference between the groups which suggests itself relates to the manner of testing. If the experimenter trained one group first, by the time he trained the second group of rats his technique might have sufficiently changed to affect their scores. It should, therefore, be pointed out that members of the same groups were tested at quite different times and members of different groups were tested at the same time. The testing procedure is rather tedious and only a few animals can be tested in an afternoon. A comparison of the records of rats which were tested as much as two years apart showed no differences in scores. We also have compared records taken by two research assistants and found that their data were in striking agreement. For such comparisons we also had data available from the large group of normal animals on which we reported in the preceding study.

(b) Analysis of Pre- and Post-Operative Scores of Group I

Comparison of the average scores made by Group I before and after operation show no marked difference. On the simple reasoning problem, the average number of correct responses in 20 trials was $18.38 \pm .20$ before operation and $18.28 \pm .25$ after operation, with chance expectancy equal to 10. In a previous study (Maier, 1932) in which both pre- and post-operative records were taken, it was found that scores were not markedly impaired unless the lesions exceeded 22 percent. In the present study, the average lesion was 16.1 percent and all but two of the animals suffered lesions less than 22 percent in size. The largest lesions were 23.0 and 26.8 percent and the post-operative scores made by the animals with these lesions were 20 and 13, respectively (see Table 1).

The fact that no deterioration is apparent in the group as a whole seems to be due to the fact that 12 of the 29 animals bet-

tered their records in the post-operative tests. The 13 rats with lesions below the average of the group made a pre-operative score of 17.8 and a post-operative score of 18.4, whereas the 16 rats with lesions above the average made a pre-operative score of 18.8 and a post-operative score of 18.2. Thus the animals with smaller lesions actually improved, whereas the animals with lesions above the average showed a slight reduction in score. The inadequate preliminary period and the smaller lesions used thus seem to explain the discrepancy between the results of the present and the previous investigations.

Our main purpose in this study has been the analysis of behavior in the complex problem. Because it was believed that the more complex problem would handicap operated animals, the lesions were kept rather small. However, even on this problem, the effect of the lesion was slight. Before operation, the group average was $11.00\pm.27$ correct responses (55.0 percent) with chance expectancy equal to 5, whereas after operation the score was $10.24\pm.30$ (51.2 percent).

Since the problem contained two choice points, as described in the analysis of the behavior of normal rats on this problem (Maier, 1938), we may also compare the pre- and post-operative scores at the two choice-points. At each choice-point, chance expectancy is equal to 10. At the first choice-point the pre-operative score was $12.52\pm.31$ as compared to a post-operative score of $12.31\pm.28$. At the second choice-point, the pre- and post-operative scores are $16.38\pm.30$ and $16.0\pm.28$. Thus as a group, no reliable difference in score is found between the pre- and post-operative scores, no matter what criterion is used for comparison.

An analysis of changes in individual records, however, discloses certain differences. In Table 5, we have grouped the animals as follows: (1) Those whose score improved 2 points or more after operation; (2) Those whose score dropped 2 points or more after operation; (3) Those whose score remained within 2 points of the pre-operative score. Scores at each of the two choice-points are also included. It will be seen that 7 animals improved their score after operation, 13 showed a lowered score and 9 had scores which remained about the same.

TABLE 5

Changes in Score after Operation

RAT	LESION	PRE-OPERATIVE SCORE			POST-OPERATIVE SCORE		
		1st choice point	2nd choice point	Perfect runs	1st choice point	2nd choice point	Perfect runs
Rats which showed improvement in score after operation							
5M	7.4	10	20	10	18	16	14
30M	13.1	10	15	9	12	19	11
42M	16.3	10	19	9	14	17	14
10F	16.6	8	16	8	14	20	14
7F	19.1	12	12	8	12	20	12
33M	19.6	10	17	10	16	15	13
16M	21.3	7	18	7	12	16	10
Average....	16.20	9.57	16.71	8.71	14.00	17.57	12.57
Rats which showed reduction in score after operation							
4M	11.7	12	18	12	10	18	10
11F	14.5	16	16	14	8	12	8
35M	14.9	14	17	12	12	15	9
19M	15.4	13	20	13	13	17	11
1M	16.3	14	18	14	10	14	8
9F	16.5	14	18	14	14	14	10
27M	16.5	17	18	15	12	16	12
44M	16.5	17	17	14	13	16	9
40M	17.0	15	17	13	13	12	8
17M	17.2	16	17	13	13	18	11
2M	18.4	14	20	14	10	20	10
21M	21.7	11	12	10	12	13	8
25M	23.0	13	12	11	14	11	8
Average....	16.89	14.31	16.92	13.00	11.85	15.08	9.38
Rats which showed about the same score after operation							
41M	10.7	14	16	11	12	17	10
45M	11.7	14	16	11	13	17	12
29M	11.7	13	14	10	16	13	9
23M	11.9	10	12	9	13	14	9
13F	13.6	12	16	8	8	18	8
8F	13.7	12	14	10	10	18	10
20M	13.7	13	17	10	13	15	10
15F	19.8	12	14	10	10	16	10
22M	26.8	10	19	10	10	17	9
Average....	14.84	12.22	15.33	9.89	11.67	16.11	9.67

The rats which showed improvement after operation made a very poor pre-operative record. At the first choice-point their score was 9.57 correct (slightly below chance); at the second choice-point, 16.71; and at both choice-points, 8.71 correct (chance expectancy equals 5). After operation the corresponding scores were 14.00, 17.57, and 12.57, respectively. Thus the poor showing before operation is largely due to the fact that the animals failed to react to the problem as a whole, but solved it by relating the isolated experiences to the second choice-point only. This was found to be characteristic of inferior normal animals.

Examination of the individual scores of this sub-group shows that 6 of the 7 animals made no better than chance performance on the first choice-point. Only 2 of the 22 rats of the other two sub-groups made scores of chance or less at any of the choice-points before operation.

After operation, all of the 7 animals which improved their scores made better than chance performance at the first choice-point. It, therefore, follows that after operation the problem was reacted to as a whole.

To determine whether the operation was responsible for this change in the attack on the problem or whether the change in attack appeared toward the end of the pre-operative test period, we compared the behavior at the first choice-point during the first 10 and the second 10 pre-operative trials. This analysis showed that 4.1 responses were correct during the first 10 trials and 5.4 during the second 10 trials. Thus, within the pre-operative test period, the attack on the problem began to change. As a consequence of this change in attack, the totally correct responses rose from 3.7 for the first 10 trials to 5.0 during the second 10 trials (chance expectancy equals 2.5).

This delay in the appearance of the more successful attack on the problem is similar to that reported by Grether and Maslow (1937) on monkeys. They found that certain monkeys failed to solve their problem immediately but later succeeded. As in the present situation, learning could not explain the improved score and they termed the behavior phenomena of such animals as "delayed insight."

In the case of rats which showed a reduction in score after operation, the pre-operative score at the first choice-point is 14.31 as compared to a post-operative score of 11.85. At the second choice-point, these scores are 16.92 and 15.08, respectively. For the problem as a whole, the scores are 13.00 and 9.38, respectively. Again the change in behavior is largely at the first choice-point, but only 3 of the 13 animals made a chance post-operative score at this choice-point. Thus the animals as a group have not lost their tendency to react to the problem as a whole, but have shown a general decrease in accuracy.

The rats which made similar scores before and after operation showed pre-operative behavior intermediate between that of the other two groups. Their average pre- and post-operative scores at the first choice-point were 12.22 and 11.67, respectively; at the second choice-point, 15.33 and 16.11, respectively; and on the problem as a whole, 9.89 and 9.67, respectively. There is thus no marked change in the attack on the problem after operation.

The extent of brain injury seems to bear no relation to the trend of score after operation. For animals which improved, the average lesion was 16.2 percent; for those which showed a reduced score, 16.9 percent; and for those which showed no change, 14.8 percent. Any deterioration that was present because of the operation seemed to be offset by improvement in scores because of the delayed reactions to the problem as a whole.

In order to further study the amount of improvement during the testing period, we have compared the number of totally correct responses during the first 10 and the second 10 test trials. These results are shown in Table 6. It will be seen that the pre-operative score for the whole group of rats rose from 51.0 percent correct for the first 10 trials to 59.0 percent correct for the second 10 trials. The post-operative scores show no such improvement, being 50.7 percent correct for the first 10 test trials and 51.7 percent correct for the second. If we compare the score made during the last 10 trials of the pre-operative test with the post-operative score, some deterioration becomes apparent.

All of the sub-groups, however, do not show such an improvement in score during the pre-operative test period. The rats which showed a reduction in performance after operation apparently reached their maximum performance at the outset, and it is in their case that the detrimental effects of the brain injury is not offset by better adaptation to the test situation. Even the rats which showed no change in their total score show some evidence of deterioration if their second 10 trials of the pre-operative record are used for comparison with the post-operative trials.

TABLE 6

Comparison of Scores during First and Second Half of Test Period

Group I subdivided according to the...............	BEFORE OPERATION		AFTER OPERATION	
	Score on problem as a whole		Score on problem as a whole	
Type of change in score after operation.............	1st 10 trials	2nd 10 trials	1st 10 trials	2nd 10 trials
1. Cases showing improved score........	3.7	5.0	6.7	5.9
2. Cases showing reduced score..........	6.5	6.5	4.2	5.2
3. Cases showing no change greater than 1 point in score.....................	4.2	5.7	5.0	4.7
Average of all cases...................	5.10	5.90	5.07	5.17
Percent correct (chance 25%)..........	51.0	59.0	50.7	51.7

(c) Analysis of Post-Operative Scores of Group II

In Table 7 we have presented the post-operative scores made by rats in Group II on the simple and complex test situation. Sixteen of the twenty-six animals were also given pre-operative tests on the simple problem. Their average pre-operative score was $17.0 \pm .16$ correct runs in 20 trials (85.0 percent).

After operation the score of Group II as a whole was $15.23 \pm .49$ correct (76.2 percent) which is somewhat lower than that made by Group I. However, this group contains 8 animals with lesions which exceeded 22.0 percent. The average post-operative score of these 8 animals is 11.4 correct (57.0 percent) which is not greatly in excess of chance performance. The pre-operative score for these same rats is 16.9 (84.5 percent). The average

post-operative score for the remaining 18 animals of this group
is 16.9 which is approximately equal to the pre-operative score

TABLE 7

*Post-operative Scores Made by Rats Not Tested on Complex Problem before Brain
Injuries (Group II)*

RAT	PERCENT OF DESTRUCTION	SIMPLE PROBLEM		COMPLEX PROBLEM		
		Pre-operative score	Post-operative score			
92M	8.4		17	13 — 10 — 7		
90M	9.6		15	13 — 10 — 5		
71M	10.0	16	17	9 — 16 — 6		
98M	10.2		20	13 — 10 — 7		
94M	11.2		19	11 — 10 — 6		
67M	11.2	18	18	4 — 13 — 2		
91M	11.7		18	9 — 8 — 6		
97M	12.2		19	11 — 10 — 8		
96M	12.6		16	10 — 10 — 5		
66M	13.2	16	16	8 — 14 — 7		
78F	14.8		20	8 — 14 — 6		
95M	15.0		13	12 — 12 — 6		
79F	15.5		11	9 — 10 — 3		
75M	17.2	18	16	12 — 15 — 9		
68M*	19.2	18	18	13 — 15 — 12		
77M*	19.2	17	18	14 — 12 — 10		
76M	20.0	16	16	9 — 12 — 7		
73M	21.0	18	18	7 — 17 — 6		
64M	22.7	18	18	11 — 13 — 5		
63M	23.3	16	11	8 — 9 — 5		
70M	23.3	16	8	7 — 8 — 3		
62M	23.4	16	10	12 — 13 — 8		
65M	24.3	17	16	13 — 9 — 5		
60M	24.9	18	13	5 — 11 — 4		
69M	28.0	16	8	6 — 8 — 3		
61M	31.9	18	7	9 — 9 — 4		
Av.............	15.7	17.0	15.23	9.85	11.46	5.98
S.D.............	6.49	.94	3.62	2.68	2.53	2.20
P.E. Dist.......	4.38	.63	2.44	1.81	1.71	1.48
P.E. M.........	.87	.16	.49	.36	.34	.30

* Cases which refused to run on several trials. Their scores for the 20 trials
are based upon the proportion of correct responses for the trials in which they ran.
If refusal to run is an error, the scores of these cases are too high.

of the whole group. Thus the loss in ability on the simple test
is primarily due to cases with lesions exceeding 22 percent.

The post-operative score of the ten animals not given pre-operative tests is 16.8 correct in 20 test trials (84.0 percent). This score is but slightly below that of normal rats when first confronted with this problem. Success on the simple problem seems therefore to be quite independent of previous experience.

On the complex problem these same animals made a score of 5.9 correct responses which is but slightly above the chance expectancy score of 5.0. On the complex problem the performance of Group II is quite unlike that of Group I which received pre-operative training on the problem and made a score of 10.24 in the post-operative tests.

We have already discussed the inferior post-operative scores on the complex problem made by this group of rats. We may now raise the question whether this inferior performance is due to delayed solutions. We found that animals in Group I improved their pre-operative performance during their first battery of 20 tests, but did not do so after operation. This suggests that they either reached their maximum performance by the time the post-operative tests were given, or were unable to progress beyond their pre-operative level after operation. Since the rats in Group II had no opportunity to reach a certain level of performance before operation, an analysis of their improvement during their first 20 test trials is required. Dividing the test trials into two groups reveals that during the first 10 trials an average of 3.00 responses were correct and during the second 10 trials an average of 2.96 responses were correct. It appears that the rats in Group II failed to improve during the testing period, and we therefore cannot attribute their poor showing to delayed solutions. Rather they seem unable to achieve whatever function is necessary for the integration of isolated experiences.

Since this group of animals is distinctly inferior in their behavior to that of normal animals and the operated animals in Group I, it is of interest to analyze their performance to determine in what manner they are inferior.

In Table 7 we have given the scores made by these animals at the first and second choice-points. Their average score at the first choice-point is $9.85 \pm .36$ and at the second $11.46 \pm .34$.

These values approximate chance expectancy (10 correct). Only 12 of the 26 rats made more than 10 correct responses at the first choice-point, and 13 made more than 10 correct responses at the second. If we impose as the criterion for passing the test a score better than chance at each choice-point as well as more than 5 perfect responses, then only 4 (15.4 percent) can be credited with passing the test. Of the operated rats in Group I, 21 of the 29 rats (72.4 percent) passed this criterion, and 43 of the 56 normal

TABLE 8

Animals Grouped According to Types of Score Achieved

GROUP	NUMBER OF RATS	CORRECT RESPONSES AT FIRST CHOICE-POINT	CORRECT RESPONSES AT SECOND CHOICE-POINT	AVERAGE NUMBER OF TRIALS IN WHICH		
				Both choices were correct	One choice was correct	Both choices were incorrect
A. Rats which made a better score at the first choice-point than at the second	5	13.20±.27 (66.0%)	10.20±.66 (51.0%)	6.80±1.24 (34.0%)	10.19 (51.0%)	3.01 (15.1%)
B. Rats which made a better score at the second choice-point than at the first	11	8.36±.60 (41.8%)	13.45±.48 (67.3%)	6.09±.80 (30.5%)	9.86 (49.3%)	4.05 (20.3%)
C. Rats which made similar scores at the two choice-points (within one point of each other)	10	9.80±.61 (49.0%)	9.90±.32 (49.5%)	5.50±.37 (27.5%)	8.85 (44.3%)	5.65 (28.3%)

rats (76.8 percent) studied (Maier, 1938) did so on their first 20 tests.

The average score at the two choice-points does not, however, characterize the behavior of individual animals. Instead of making approximately chance scores at each choice-point, many made scores better than chance at one of them. In Table 8 we have grouped the animals according to their reactions at the choice-points.

As in the previous study (Maier, 1938), Group A consists of rats which made a better score at the first choice-point than at

the second, Group B of rats which made a better score at the second choice-point than at the first, and Group C of rats which made scores within one point of each other at both choice-points. When the rats are typed in this manner, we readily see that the operated animals succeeded only in solving half of the problem. Group A, consisting of 5 rats, made 66.0 percent correct responses at the first choice-point and 51.0 percent (approximately chance performance) at the second choice-point. Group B consisting of 11 rats, made 41.8 percent correct responses at the first choice-point and 67.3 percent, at the second. Group C consisting of 10 rats, made approximately chance scores at both choice-points (49.0 percent at the first and 49.5 percent at the second). Group C, by reacting equally to both halves of the problem, failed to pass either half and made the fewest number of perfect runs. It only made 27.5 percent runs which were correct at both choice-points, which record approximates a chance score of 25 percent, whereas Groups A and B made 34.0 and 30.5 percent perfect responses, respectively. The operated rats which react to part of the problem adapted slightly better to the situation than did animals which reacted equally to both parts. This is in contrast to our study of normal rats in which we found that Type C reactions made for the greatest number of perfect runs (see p. 19, Maier, 1938). The study of normal rats also showed that none of the groups as a whole made chance scores at any of the choice-points. Only a few individuals showed such performance and these were found to be inferior individuals.

Type C responses of the operated rats differ from those of the normals in that the operated rats made chance scores at both choice-points, whereas the normals made scores definitely above chance (72.0 and 73.7 percent) at the two choice-points. Thus we may say that the Type C response of the operated animals of Group II were adaptive reactions to neither of the choice-points, whereas the Type C reactions of normal rats were adaptive reactions to both choice-points.

Thus we may group the behavior of animals according to whether they react to (1) the problem as a whole, (2) a part of the problem, and (3) no part of the problem.

We have already found that the previous day's run influences the behavior of normal rats according to the manner in which they attack the problem. In Table 9 we have made a similar analysis of the operated rats of Group II. (For review of method of analysis, etc., see pp. 15–20.)

A change in the bridge at the first choice-point has the following effects:

1. Group A made a score of 47.4 percent at the first choice-point, showing that it inadequately adapted to the change. Its

TABLE 9

Influence of a Change in the Problem on Accuracy of Performance

GROUP	NUMBER OF RATS	PART CHANGED	NUMBER OF CASES	SCORE (PERCENT CORRECT CHOICES)		
				First choice-point	Second choice-point	Both choice-points
A. Score better on first choice-point than on second	5	1st	19	47.4	63.2	26.3
		2nd	30	83.3	53.3	46.7
		Both	33	57.6	36.4	18.2
B. Score better on second choice-point than on first	11	1st	41	26.8	87.8	24.4
		2nd	74	71.6	77.0	55.4
		Both	84	21.4	48.8	8.3
C. Score nearly equal on the two choice-points (within one point)	10	1st	39	25.6	59.0	20.5
		2nd	65	61.5	70.8	47.7
		Both	78	46.2	24.4	9.0
Average....................	....	1st		33.3	70.0	23.6
		2nd		72.1	67.8	49.9
		Both		41.7	36.6	11.8

score at the second choice-point is, however, 63.2 percent, showing that it can reproduce its previous day's run over the unchanged bridge with some success.

2. Group B, with a score of 26.8 percent at the first choice-point, is even less successful in adjusting to this change, showing that it reproduces its behavior of the day before at this choice-point despite the fact that it has been shown the change in the bridge. Its behavior at the second choice-point is 87.8 percent correct. It thus reproduces at its preferred choice-point quite effectively.

3. Group C, with a score of 25.6 percent at the first choice-point, also shows no ability to adapt to the change although it reproduces with some success as is shown by its score of 59.0 percent at the second choice-point. This score is similar to that of Group A, which also showed little tendency to react to the second choice-point. That it is slightly inferior to the score of Group A is to be expected when we remember that Type C performance is resorted to by the least adaptive animals.

The general indication is that the previous day's combination greatly influences the behavior of all animals. Not even the animals which react primarily to the part of the situation which is changed succeed entirely in their adjustment, although they do better than the others.

A change at the second choice-point has the following consequences:

1. Group A, with a score of 83.3 percent at the first choice-point, is superior to the other two groups. This is to be expected when we consider that this group reacts to the first half of the problem and must merely duplicate the run of the previous day at this choice-point. At the second choice-point its score of 53.3 percent is approximately chance, showing inability to adapt to this change.

2. Group B makes a score of 71.6 percent at the first choice-point and 77.0 percent at the second, thus showing superior performance at the changed choice-point. This is the only situation in which the behavior of the operated animals is qualitatively like that of normal animals.

3. Group C makes scores of 61.5 and 70.8 percent at the first and second choice-points, respectively, showing slightly better performance at the changed choice-point.

As in the case of normal animals, a change in the second choice-point is more likely to be reacted to by all groups than a change in the first choice-point. The average number of perfect runs for all three groups is 23.6 percent for a change at the first choice-point (chance expectancy) and 49.9 percent for a change at the second choice-point. For normal rats the corresponding scores are 55.4 and 78.1 percent.

A change at both choice-points has the following effect on the groups:

1. Group A makes a better score at its favored choice-point than at its unfavored choice-point (57.6 percent as compared with 36.4 percent).

2. Group B also makes a better score at its favored choice-point (48.8 percent as compared with 21.4 percent).

3. Group C with a score of 46.2 percent at the first choice-point surpasses its score of 25.6 percent when the first choice-point alone was changed. Apparently the double change has so confused this group that it makes a chance score, rather than reacts on the basis of the previous day's combination. At the second choice-point its score of 24.4 percent is sufficiently below chance to show that instead of reacting on a chance basis it reacts on the basis of the previous day's run.

As in normal rats the double change is the most difficult one. The number of perfect runs is well below chance expectancy, showing the marked influence of the previous day's behavior. The scores in terms of perfect runs for the operated Groups A, B, and C are 18.2, 8.3 and 9.0 percent, respectively. The corresponding scores for normal rats are 27.5, 33.9, and 37.8 percent.

As in the case of normal rats, Groups A and B consistently express their preferences at one of the choice-points although they do not sufficiently adapt to make much better than chance scores at these choice-points. Their scores at the non-favored choice-points are definitely below chance, showing reactions based on the previous day's run.

Considering the effects of changes in bridges on the operated group as a whole, we find that the double change reduces the number of perfect runs to 11.8 percent. The average score for a change at the first and second choice-points alone is 36.8 percent $\left(\dfrac{23.6 + 49.9 \text{ percent}}{2}\right)$ which is more than three times as great as the score resulting from changes at both choice-points. In the case of normal rats the single change resulted in a score two times as great as the double change, showing that the double change complicates the problem relatively more for operated rats than

for normal rats. These operated rats are therefore not only more susceptible to the influence of the previous day's runs than are normal rats, but they are also more disoriented when the day's test is complicated by a double change.

We have already pointed out that the operated rats tended to react to part of the problem rather than solve the problem as a whole. This is further borne out by the fact that the score at the first choice-point is below chance (41.7 percent) when both choice-points are changed as well as when the first choice-point alone is changed (33.3 percent). Thus the addition of a change at the second choice-point does not lower the score at the first choice-point. However, the score at the second choice-point is lower for the double change (36.6 percent) than for a change at the second choice-point alone (67.8 percent). This shows that in some cases at least the addition of a change at the first choice-point further complicates the problem. In such cases the problem as a whole determines the reaction, and the behavior cannot be regarded as purely a reaction to part of the situation.

Since changes in the first part of the problem are more disastrous than changes in the second part of the problem, we have evidence showing that the behavior pattern tends to be built up in the forward direction, as was the case of the normal rats. Operated rats seem to accomplish this by running the first part of the problem in terms of their previous day's run. Thus from Table 9 it is apparent that each of the three groups made a score better than chance at the first choice-point when the second choice-point was changed and the first was left unchanged. The general average in this case was 72.1 percent. When, however, the first choice-point was changed, the performance at this choice-point dropped to 33.3 percent correct.

The second part of the problem was, however, less susceptible to the influence of the previous day's run. When this choice-point remained unchanged, all groups made better than chance scores, but only Group B showed a score decidedly above chance. The average for the three groups was 70.0 percent correct at the second choice-point when it remained unchanged and 67.8 percent when it was changed. Thus the second part of the problem was

reacted to about equally well in both cases, showing that the previous day's behavior at this choice-point was not the determining factor.

We may therefore regard the apparent forward construction of the solution by these rats as accomplished largely because habitual responses dominated the behavior at the first choice-point, whereas some reorganization of experience occurred in connection with the second choice-point.

Since the problem is not solved as a whole through the reorganization of experience, we cannot regard the solution as being constructed in the forward direction in the case of the operated rats of Group II. Normal rats, however, do not tend to react in an habitual manner at either choice-point, and, therefore, must reorganize their experiences in the whole problem. In their case the evidence points to the forward construction.

DISCUSSION OF "DIRECTION"

A comparison of the two operated Groups I and II, reveals a marked difference in the ability to solve a problem requiring the integration of four separately given experiences. Group I, with pre-operative training in integrating different past experiences, retains its ability to make similar integrations after operation. Group II, without pre-operative training, however, almost completely fails to acquire this ability. Since the difference between the groups is not due to selection or differences in the nature of the lesions, we are forced to conclude that animals are able to carry something through a brain injury which they are incapable of acquiring after it. This something which is retained is essential to the solving of our problem, yet it cannot be regarded as a specific memory because specific memories would lead to incorrect responses. As a matter of fact, specific memories may be lost through an operation, but can again be acquired. The present experiment reveals the retention of something which an operation does not impair, but which is prevented from being acquired after operation.

This effect is in accordance with what one might expect if one postulated a special mechanism which we have referred to as

direction. In the introduction we pointed out that if an organizing mechanism existed, it should be possible to isolate its function.

Suppose we regard a *direction* as a specific dynamic state which is set up in a problem situation and which acts upon the background of memories determining which will become organized into the figure (or solution) and which will remain in the background. When once set up it tends to persist and thus produces similar solutions even when the elements are radically different. In consciousness, its presence may give rise to the feeling that two things are related, without a specific relationship being apparent.

After a time this feeling will be followed by the specific experience of a relationship, which will be a solution. The presence of this feeling makes for similar attempts at solutions in other situations and thus gives rise to habituation. Sometimes this habituation may be adaptive, at other times it may block a successful solution.

If previous experience on our problem sets up a tension in the rats which aided the formation of the solution on one occasion, it follows that similar problems would be solved on the basis of this same tension. Only the specific combination would be different from one instance to the next.

This tension being of a general nature would not be subject to the same brain processes as specific memories. It could, therefore, very well survive a brain injury which would abolish habits. The setting up of this tension, however, would be quite a different matter and might reasonably require considerable brain tissue. It takes more ability, for example, to solve a problem than to understand a solution which some one shows us. After one has experienced some other person's solution, however, one can solve other problems of a similar nature. Thus a direction once established may be useful to the rat on similar problems, but it should not transfer to problems requiring a different direction. It should, therefore, follow that if our two groups were transferred to a radically different problem, the difference between them should disappear.

In the studies on human subjects (Maier, 1930, 1931) we have

found that problems requiring new directions are very difficult. If instructions are given which aid in setting up a direction, a solution can be made to appear even though no element or memory has been added.

We, therefore, are inclined to identify the process which we have called *direction* in the thinking of humans with that something which survives a brain injury in the rat but which cannot be set up after brain injury.

Duncker (1935) regards the concept of *direction* as unnecessary for a theory of creative thinking, since he believes the situation sets up the dynamic process which is essential in the selective process.   In so far as he believes reasoning requires a dynamic field process, we are in agreement, but in so far as he regards the dynamic field as entirely established in the organism by the problem situation, we disagree.   It is our contention that a direction process which is intrinsic to the organism is a necessary postulate, although we recognize that direction is influenced by the problem situation.   The present experiment supports our contention because, according to Duncker, the two operated groups with the same neural mechanisms should show the same kind of behavior.   The same problem situation should arouse like dynamic processes in two groups of animals which are equated as far as their neural make-up is concerned.   Since they do not, a dynamic process intrinsic to the animal must have been carried through the operation.   We regard this fact as adequate reason for the postulation of a separate type of mechanism.

Claparède (1934) has recently analyzed the reasoning processes in terms of a mechanism he calls the *hypothesis* and which he regards to be similar to what we have called *direction*.   If I understand him correctly, these concepts are not identical.   He seems to regard *hypothesis* as a sort of a hunch which is tested.   Many *hypotheses* may be brought to bear on the problem until one is found to function.   In this sense the *hypothesis* is similar to concept formation in which various concepts are tried out before one is found to work.   This sort of thing may occur, but we are still faced with the problem of how these *hypotheses* are formed. Some may arise from past experience as remembered solutions

(and in such cases they are not new); others are formed for the first time and it is our interest to describe the mechanism which causes such hypotheses to arise.

Thus we are concerned with the process involved in the formation of hypotheses. We should regard their appearance as solution patterns and should regard the formation of each new *hypothesis* as an act of reasoning. The rejection of *hypotheses* is a different aspect of the problem solving behavior, and I should not regard success in solving a problem as the criterion of reasoning. Rather reasoning is taking place whenever a certain kind of process is in progress.

Human studies on reasoning have frequently postulated a process which serves to select the elements of past experience which are appropriate in a test situation. The *determining tendency* of Ach (1905) and the atmosphere effect of Woodworth and Sells (1935) are examples of specific mental sets aroused in the problem situation. These concepts imply dynamic functions which influence ideas but are not ideas themselves. Sells (1936) regards the atmosphere effect as unconscious. Such selective functions are all closely related with *hypothesis* formation and *direction*. Each has seemed to be a necessary postulate to an experimenter in order to account for selective functions in different types of experimentation. Perhaps they refer to the same mechanism. It is merely a question of whether instructions to reproduce "nouns" when a stimulus word is given, is the same kind of selective process which causes a person to make an error in a syllogism which he would not have made if a similar syllogism had not been solved previously, and whether these are the same as the directive influence which gives rise to a new solution. In human studies it has been found that a selective process alone is inadequate for solving new problems. Our concept of *direction*, therefore, has been conceived as an integrating function, and it is through the integration of certain elements in past experience that selection is achieved. Since the rats were required to integrate past experiences and not merely to select them, we are inclined to regard purely selective concepts as inadequate.

Our study also demonstrates the similarity of higher processes

in rats and men, and we hope it shows that mentalistic concepts and introspective procedure are unessential in the study of reasoning. An emphasis on mentalistic concepts results in an unnecessary separation of animal and human work. This seems undesirable since many crucial tests of theory can be made with animal subjects.

SUMMARY

Two groups of rats with cortical injuries were tested with respect to their ability to solve a complex problem requiring the reorganization and integration of four separately given experiences. Twenty test combinations were used, each combination being different from that of the previous day in one or two ways. The scores were based upon the number of correct responses in the 20 test runs. Group I consisted of 29 animals, each of which was tested before as well as after operation. Group II consisted of 26 animals, each of which was tested after operation only. The simple reasoning test was also given after operation and in most cases before operation as well, in order to make possible the comparison of problems differing in complexity.

The purpose of the study was to determine whether an organizing or integrating principle such as we have called *direction* functioned in a problem situation. It was postulated that a process could be set up before operation which might survive a brain injury, but which could not be established in the absence of sufficient cortical tissue. It was believed that a dynamic process having to do with the selection and integration of past experience might be affected differently than memory traces. If this were the case, it would lend support to the notion that an integrating function was separate and distinct from the elements integrated and that a reorganization in experience was not produced by forces inherent in these elements.

The following conclusions may be drawn from a comparison of the post-operative scores made by the two groups of rats.

1. The distribution of scores made by Groups I and II show practically no over-lapping. The scores of Group I are uniformly above chance (average 51.2 percent correct when chance

expectancy is 25.0 percent) whereas the scores of Group II fall on either side of the chance score (average 29.9 percent correct).

2. The pre-operative scores of the two groups on the simple reasoning problem showed no marked difference between the groups.

3. A comparison of the cortical injuries suffered by the two groups showed that the amount, the locus, the shape, the depth, and the involvement of subcortical structures were not responsible for the difference in score.

4. It was concluded that the pre-operative training of Group I was responsible for the superiority of Group I over Group II.

An analysis of the pre- and post-operative scores of Group I brought out the following.

1. Cortical injury resulted in no deterioration on either the simple or the complex test situations when pre- and post-operative scores of the group as a whole are compared. However, the range of distribution of scores on the complex problem decreased after operation due to an increase in the scores of the animals making low scores and a decrease in the scores of animals making high scores.

2. Analysis of this change in score revealed that some animals in the pre-operative tests began solving the problem in part but later reacted to the problem as a whole. The score improved when the problem was reacted to as a whole, and this improved technique was used after operation. As a consequence the post-operative test period measured reactions to the problem as a whole and was a measure of the maximum performance of these animals, whereas the pre-operative test period measured the maximum performance of such animals only during the later part of the testing period.

3. Improvements in score did not occur during the post-operative tests and the techniques used were those developed during the pre-operative tests.

4. When improvements in score arising during the pre-operative test period are discounted there is evidence of deterioration because of cortical injury. This deterioration is not associated with the amount of brain destruction, but the injuries were in no case extensive.

5. The data of this group support the contention that a technique in problem solving may be developed before brain injury which will be used after brain injury but which cannot be developed after marked brain injury.

From a detailed analysis of the performance of Group II the following conclusions may be drawn.

1. Denying this group of animals pre-operative experience had a much less pronounced effect on the post-operative performance on the simple reasoning test than on the complex reasoning test.

2. The poor performance of this group on the complex problem showed no tendency toward improvement as is evidenced by the fact that the scores for the first and second ten test trials showed no upward trend. Thus this group as a whole showed neither immediate nor delayed solutions. Considering the individual cases, only 15.4 percent can be credited with passing the test, whereas 72.4 percent of the operated cases of Group I and 76.8 percent of all of the normal animals passed the test.

3. With respect to the scores made at each of the two choice-points, these rats may be classed into 3 groups similar to the classification of normal animals. Thus 5 rats made a better score at the first than at the second choice-point (Group A); 11 rats made a better score at the second than at the first choice-point (Group B); and 10 made practically equal scores at the two choice-points (Group C). The scores of these sub-groups show that none made a score above chance at both choice-points and Group C made a chance score at both choice-points. Each of the three groups of normal rats so classified made scores above chance at each choice-point.

4. Reacting equally well at both choice-points was the most adaptive response of normal animals, but it occurred in operated animals only when no part of the problem was mastered. Thus Group C, for normal rats, consists of animals which most adequately react to the problem as a whole, and for operated animals, it consists of those which react to no part of the problem.

5. Changes in the bridges at one or both of the choice-points revealed a marked tendency to reproduce the previous day's run. The operated rats of Group II are much more influenced by the

interfering effect of habit than are normal rats. As in the case of normal rats, changes in the bridges from day to day had different effects on Groups A, B, and C.

6. When changes were made at both bridges, operated rats tended to reproduce the correct response of the day before at the unfavored choice-point and thus made scores well below chance expectancy, whereas they neutralized this tendency at their favored choice-point and attained a chance score.

7. Since the problem was solved only in part, construction of the problem in the forward direction was impossible. What evidence there is for forward construction arises from the fact that habitual reactions dominated the behavior at the first choice-point to a greater degree than at the second choice-point.

The discussion of results is confined to a consideration of their bearing upon a mechanism we have called *direction*. Because our two groups of operated animals showed such a striking difference in ability, we believe it is necessary to postulate the existence of specific dynamic states which can be set up in rats before a brain operation but which cannot be set up after operation. Different neural stresses are essential features in the various kinds of reorganization of experience, and once one is set up, it may survive an operation and permit the solving of similar problems. Since brain injuries affect this type of process in a different manner from the way they affect memories, we regard the *direction* process as different in kind from the elements it integrates.

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PLATES I TO V

The following plates are diagrammatic reproductions of the locus, shape and magnitude of the cortical injuries of rats in Groups I and II. Within each group the rats are arranged according to the magnitude of the brain injury. The experimental number and the percent of destruction are given in the upper left hand side of each diagram. The scores attained are given in the upper right hand side of the diagram. The first line gives the pre-operative score, the second the post-operative score. When only one line is given it indicates the post-operative score. (Group I was given both pre- and post-operative tests whereas Group II was given some pre-operative tests on one problem and none on the other.) The first value in the line pertains to the simple reasoning test and represents the number of correct responses in 20 trials. The next three values separated by dashes are the number of correct responses in 20 trials in the complex problem. The first of these 3 values is the score obtained on the 1st choice-point; the 2nd, the score on the 2nd choice-point; and the 3rd, the number of perfect runs (responses correct at both choice-points). For example, rat 5M suffered a lesion which destroyed 7.4 percent of the exposed surface of the cortex. Before operation, its score on the simple reasoning was 20; after operation, it also made a score of 20. On the complex reasoning problem, its pre-operative score at the 1st choice-point was 10; at the 2nd choice-point, it was 20; and in terms of perfect runs, its score was 10. After operation, the corresponding scores were 18, 16, and 14.

GROUP I

Rat 23M
Lesion 11.9%
20 10-12-9
20 13-14-9

Rat 5M
Lesion 7.4%
20 10-20-10
20 18-16-14

Rat 30M
Lesion 13.1%
19 10-15-9
20 12-19-11

Rat 41M
Lesion 10.7%
15 14-16-11
20 12-17-10

Rat 13F
Lesion 13.6%
18 12-16-8
19 8-18-8

Rat 45M
Lesion 11.7%
18 14-16-11
20 13-17-12

Rat 8F
Lesion 13.7%
15 12-14-10
16 10-18-10

Rat 4M
Lesion 11.7%
18 12-18-12
18 10-18-10

Rat 20M
Lesion 13.7%
17 13-17-10
20 13-15-10

Rat 29M
Lesion 11.7%
17 13-14-10
16 16-13-9

Rat 11F
Lesion 14.5%
19 16-16-14
14 8-12-8

PLATE I
81

Rat 35M
Lesion 14.9%
19 14-17-12
17 12-15-9

Rat 44M
Lesion 16.5%
17 17-17-14
20 13-16-9

Rat 19M
Lesion 15.4%
19 13-20-13
19 13-17-11

Rat 10F
Lesion 16.6%
20 8-16-8
20 14-20-14

Rat 1M
Lesion 16.3%
18 12-18-10
20 10-14-8

Rat 40M
Lesion 17.0%
20 15-17-13
18 13-12-8

Rat 42M
Lesion 16.3%
18 10-19-9
19 14-17-14

Rat 17M
Lesion 17.2%
20 16-17-13
18 13-18-11

Rat 9F
Lesion 16.5%
19 14-18-14
17 14-14-10

Rat 2M
Lesion 18.4%
19 14-20-14
20 10-20-10

Rat 27M
Lesion 16.5%
20 17-18-15
16 12-16-12

Rat 7F
Lesion 19.1%
19 12-12-6
15 12-20-12

PLATE II

82

GROUP II

Rat 33M
Lesion 19.6%
19 10-17-10
17 16-15-13

Rat 15F
Lesion 19.8%
18 12-14-10
20 10-16-10

Rat 92M
Lesion 8.4%
17 13-10-7

Rat 16M
Lesion 21.3%
18 7-18-7
19 12-16-10

Rat 90M
Lesion 9.6%
15 13-10-8

Rat 21M
Lesion 21.7%
20 11-12-10
19 12-13-8

Rat 71M
Lesion 10.0%
16 9-16-6
17

Rat 25M
Lesion 23.0%
17 13-12-11
20 14-11-8

Rat 98M
Lesion 10.2%
20 13-10-7

Rat 22M
Lesion 26.8%
19 10-19-10
13 10-17-9

Rat 94M
Lesion 11.2%
19 11-10-8

PLATE III

83

Rat 67M Lesion 11.2% 18 18 4-13-2

Rat 95M Lesion 15.0% 13 12-12-6

Rat 91M Lesion 11.7% 19 9-8-6

Rat 79F Lesion 15.5% 11 9-10-3

Rat 97M Lesion 12.2% 19 11-10-8

Rat 75M Lesion 17.2% 18 16 12-15-9

Rat 96M Lesion 12.6% 16 10-10-5

Rat 68M Lesion 19.2% 18 18 13-15-12

Rat 66M Lesion 13.2% 16 16 8-14-7

Rat 77M Lesion 19.2% 17 18 14-12-10

Rat 78F Lesion 14.9% 20 8-14-5

Rat 76M Lesion 20.0% 16 16 9-12-7

PLATE IV

84

Rat 73M Lesion 21.0% 18 18 7-17-6
Rat 62M Lesion 23.4% 16 10 12-13-8
Rat 64M Lesion 22.7% 18 18 11-13-5
Rat 65M Lesion 24.3% 17 16 13-9-5
Rat 63M Lesion 23.3% 16 11 8-9-5
Rat 60M Lesion 24.9% 18 13 5-11-4
Rat 70M Lesion 23.3% 16 8 7-8-3
Rat 69M Lesion 28.0% 16 8 6-8-3
Rat 61M Lesion 31.9% 18 7 9-9-4

PLATE V

85

COMPARATIVE PSYCHOLOGY MONOGRAPHS

The Effect of Early Inanition Upon Maze Learning in the Albino Rat

BY

WILLIAM C. BIEL

COMPARATIVE PSYCHOLOGY MONOGRAPHS

COMPARATIVE PSYCHOLOGY MONOGRAPHS

THE EFFECT OF EARLY INANITION UPON MAZE LEARNING IN THE ALBINO RAT[1]

WILLIAM C. BIEL

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CONTENTS

I. INTRODUCTION

The possible effects of inanition[2] upon mental growth and function are of great interest to scientists and laymen as well,

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[1] The data of this experiment were gathered in the Psychology Laboratory of Stanford University. The writer is deeply indebted to Dr. C. P. Stone for his assistance and advice throughout the course of the experiment and in the preparation of the manuscript.

[2] The term inanition is used throughout this study to indicate in a broad sense a state brought about by the lack of food or of any foodstuff which is essential to the living organism.

1

not only because of the widespread famine and chronic under-
nourishment occurring in overpopulated regions of the world
but also because of the occasional instances of severe inanition
in children and domestic animals with which one more often
comes into close contact. Because of the easily recognized ef-
fects of inanition upon physique and bodily vigor, it is only
natural to infer that severe impairment of intellectual functions
may also follow in the wake of acute and chronic inanition. In
this respect, however, our expectations have seldom been ful-
filled. Although the findings differ among investigations in
which different types of deficiencies have been studied, as a
rule the results have shown the organism to be very resistant to
any deleterious effects of malnutrition that can be detected by
standard tests of mental ability, whether we are dealing with
man or the lower animals.

It has been demonstrated in the experiments of Anderson and
Smith (2), (3), Ruch (30), and Koch and Warden[3] (16) that
food deprivation of a quantitative type when started after the
time of weaning, does not have a deleterious effect upon the maze
learning of rats and mice. In fact, for most measures of learn-
ing the deprived animals were found to be slightly superior to
the controls. This latter result may well have been due to an
increase in motivation in the experimental groups over that of
the control groups.

In experiments in which a deficiency in vitamin B-complex
(or in either of the specific components of vitamin B, i.e., B_1
or B_2) has been brought about in rats, different degrees of injuri-
ous effects have been shown in the maze learning of the animals
so treated (22), (23), (24), (4), (10), (20), (21), (26), (28), (25),
(27). As Bernhardt (4) and Poe, Wood, Poe, and Muenzinger
(28) have pointed out, when some organization of these results

[3] Although Koch and Warden (16) state that their mice were stunted from
birth, they only describe the type and amount of standard diet fed to their con-
trol and experimental groups after weaning. Nothing is stated about the method
of undernourishing the young before they were weaned. Since the young are
not capable of eating the standard diet until the time of or just before weaning,
it is assumed here that they were allowed to nurse normally until that time.

on vitamin B deficiency is attempted, it appears that the injurious effects are greatest when the deficiency occurs during the nursing period. The more remote the period of deficiency is from the nursing period, that is, when the deficiency occurs during the prenatal growth of the young or after the time of weaning, the less significant appear to be the detrimental effects upon maze learning. This would indicate that during the nursing period an adequate diet was possibly more important than during other periods of life for good maze performance.[4]

When one attempts to find some important developmental changes taking place in the rat during the nursing period which might be affected by malnutrition and which when injured at this time might affect the subsequent learning of the animal more than when injured at any other time, one of the logical tissues to investigate is the nervous system. It is of probable importance because, as Lashley (16) and many others have shown, it is so closely allied with learning. An inquiry into the anatomical and physiological changes that take place in the nervous system with age shows that the nervous system of the rat continues to develop rapidly from birth up to about three weeks of age (1), (8), (33), (37), or to the customary weaning time. The number of cortical cells increases up to that time. In addition to mitosis, gradual changes take place within the cells. There is a general differentiation of the cell structures and a gradual change in the chemical composition of the cells, as indicated by the staining reactions.

Numerous facts are also known about the anatomical changes that take place in weight and structure of the brain of the rat as a result of general inanition (15). When severe inanition is

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[4] In a recently published experiment by Bernhardt and Herbert (5) an attempt was made to test the possibility that an early deficiency in the vitamin B-complex might detrimentally influence later maze learning in the white rat more than a similar deficiency introduced at a later period in the rat's development. Although the results show the mean performance scores for the early deficient group to be consistently inferior to those for the late deficient and the control (normal) groups, none of the differences between the scores are statistically significant.

begun after the period of the rapid development of the nervous system is completed, the loss in brain weight is only slight and the effects upon brain structure are more or less variable, differing from severe degenerative effects to only slight structural changes. In the case of young rats undergoing inanition from birth for prolonged periods of time, there is a steady increase in brain weight that is only slightly less than the increase in that of normal animals of the same chronological age (34), (35), (38). In the case of structural changes in the brain, the findings show that in these young rats (a) the individual cortical cells are smaller in size although the number of cells appears to be undiminished, and (b) the myelinization of the nerve fibers is considerably lessened (38).

These changes found in the case of young rats subjected to severe inanition from birth might possibly be very influential in altering the functioning of the nervous system as measured by the rat's ability to perform in difficult learning situations. Just how influential these and other changes are has not been determined although the matter is of great theoretical and practical importance.

The purpose of the present experiment then is to study the effects of severe inanition upon maze learning in the white rat when the conditions of inanition are imposed at birth and maintained a little beyond the normal age of puberty.

II. TECHNIQUE

1. Measuring Instruments Used

As learning problems, two well-known mazes were used.

a. *Modified Warden U-maze.* The modified Warden U-maze has been described in detail by Husband (13). It consists of ten similar alley units which fit into each other in such a manner as to form the pattern shown in Figure 1, A. Wire doors placed near the exit of each unit were used to prevent retracing. Linoleum covered the floor on which the units rested and it was washed daily to prevent the accumulation of differential odors along the true pathway. Tomilin and Stone (41) report a reli-

ability coefficient for this maze of $+.95$ based upon error scores on odd-even trials.[5]
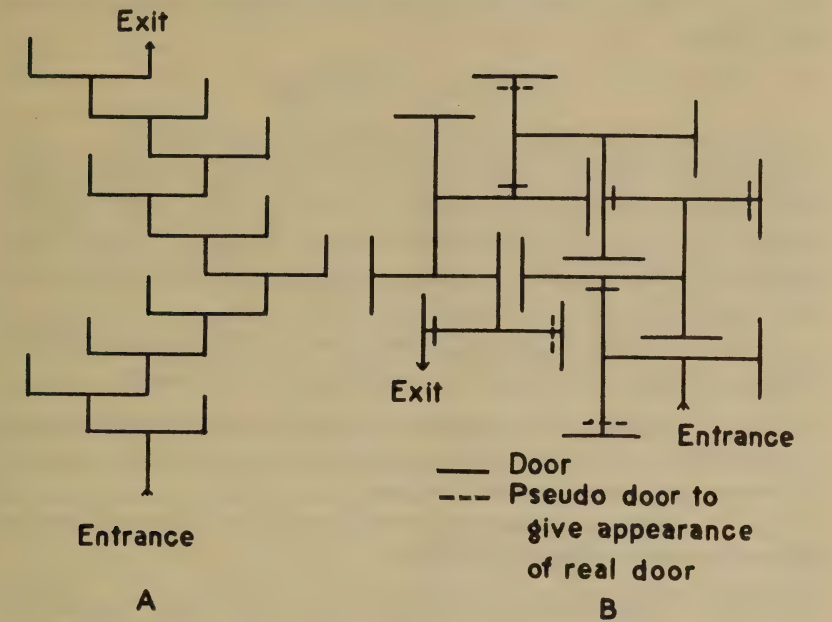
FIG. 1. *A*, THE MODIFIED WARDEN U-MAZE; *B*, THE STONE MULTIPLE-T MAZE

b. *Stone Multiple-T Maze.*   The pattern of this maze is shown in Figure 1, *B.*   Stone and Nyswander (36) have described it in detail.   The linoleum floor which was separate from the maze

[5] The reliability coefficients as found in the present experiment for the separate groups on each maze are:

MAZE	GROUP	N	RAW r. ERRORS ON SUM OF ODD VS. SUM OF EVEN TRIALS	r STEPPED UP BY SPEARMAN-BROWN FORMULA
Warden U	C_1	45	$+.92$	$+.96$
	C_2	45	$+.90$	$+.95$
	C_3	45	$+.83$	$+.91$
	E	45	$+.89$	$+.94$
Stone Multiple-T	C_1	45	$+.99$	$+.99$
	C_2	45	$+.90$	$+.95$
	C_3	45	$+.83$	$+.91$
	E	45	$+.92$	$+.96$

was washed daily.   For this maze Stone and Nyswander found coefficients of reliability ranging as high as +.97 by the method of sums of errors on odd trials vs. sums of errors on even trials (36).[6]

2. Methods of Scoring

Error and time scores were recorded for each maze.

a. *Warden U-maze.*   During the running of this maze an error was counted whenever an animal entered a blind alley to the extent of two-thirds or more of its body length.   A time score consisted of the amount of time an animal took to run from the first intersection in the maze to the food box.

b. *Stone Multiple-T Maze.*   Two types of errors were recorded during the performances of the animals on this maze.

Type I.   Errors of this type were recorded when an animal entered a blind alley to the extent of two-thirds or more of its body length in its forward progression toward the goal.

Type II.   Errors of this type were recorded for backward runs on the true pathway or into blind alleys.

Time scores for this maze were recorded in the same manner as those for the Warden U-maze.

3. Order of Presentation of the Learning Tasks

The order of presentation of the tasks was: (a) two trials per day for 5 successive days on a straightaway alley for preliminary training (food incentive); (b) two trials per day for 20 successive days on the Warden U-maze (food incentive); (c) one trial per day for 30 successive days on the Stone multiple-T maze (water incentive).   The training on one task was always completed before training was begun on the succeeding one.

a. *Preliminary Training.*   After the animals had eaten on the morning of the thirtieth day after birth, the experimenter removed all food from the cages of the normal and experimental groups.   Twenty-four hours later training was begun on the ten-foot, straightaway alley.   Moist food (Steenbock diet mixed with water in a one-to-one proportion by volume) was placed

[6] See footnote on page 5.

at the farther end of the straightaway. After making the run, each rat was allowed to feed for approximately thirty seconds. Twenty-five to thirty-five minutes later it was given a second trial, and, upon its arrival at the food box this time, was allowed to eat the full ration for the day. The time required for each run was recorded.

The desirability of giving this preliminary training has been amply demonstrated in experiments by Warden specifically covering this point (45), by Tryon (42), and by others.

b. *Warden U-maze.* On the day following the tenth trial of preliminary training (animals were now 36 days of age) training was begun on the Warden U-maze with two trials per day. At the end of the first run each animal was allowed to eat the 'reward' for thirty seconds. At the end of the second run the animal ate its full ration for the day. The interval between the two runs was from twenty-five to thirty-five minutes. As far as possible, the animals began the trials in this particular learning situation at the same time each day.

Following the completion of the forty trials on the Warden U-maze, a five day interval was allowed before beginning training on the Stone multiple-T maze.

c. *Stone Multiple-T Maze.* Twenty-four hours before training was begun on the Stone multiple-T maze, drinking water was removed from the cages. On the following day (animals were now 61 days of age) training was begun on this second maze with water as the incentive. The animals were allowed to drink their full ration of water for the day at the end of each run. This amount of thirst motivation was considerably more severe than that used by other individuals, notably Elliott (9); it gave excellent motivation. Thirty trials were given with one trial per day. Here, as in the previous learning situation, the animals were given their trials at approximately the same time each day.

4. Animals: Experimental and Control Groups

a. *Source of the Rats.* The animals used in this experiment were of an inbred stock reared in the psychological laboratory of Stanford University.

b. *Housing.* The rats were raised in cages located in a small room in which the temperature was held as nearly as possible between 70° and 80°F. This temperature range was maintained in order to insure keeping the undernourished animals warm both before and after weaning. After being weaned, the young animals were transferred to cages made entirely of hardware cloth. In order to minimize the possibility of the animals eating feces, these wire cages were set upon wooden strips that elevated them approximately one inch from a tray of shavings.

c. *Formation of Control and Experimental Groups.* One full day after the birth of each litter the young were weighed and divided into two groups, the control and the experimental groups. During the division of approximately the first two-thirds of the litters, the only factor used as a basis for determining which animals should be placed in one group or the other was that of weight. An attempt was made to make the average weight of the two groups the same. It was hoped that this method of selection would by chance put approximately the same number of males and females into each of the groups. However, as it turned out, such was not the case; more females than males were put into the experimental group. An attempt was made, therefore, to somewhat equalize this sex ratio in the last one-third of the litters which were divided into the two groups. Not only were the weights of the two groups made approximately the same (as before), but a judgment was also made as to the sex of each animal.[7] A few more males were then placed in the experimental group than in the control group. This, however, still did not finally equalize the number of each sex in each group. Of those that finished the experiment, there were in the control group 28 males and 23 females; in the experimental group, 16 males and 29 females.

Since the control group at thirty-six days of age was to be subdivided into three control groups (C_1, C_2, and C_3) for the maze learning, a large number of animals was required. In order to

[7] The technique used for determining the sex of the young animals before the differences in the accessory organs of sex were discriminable was that described by Jackson (14).

make this possible other litters of rats of the same age were added to the above original control group of animals. These additional control animals had been reared under the conditions of being with their mothers at all times until being weaned at twenty-five days of age. After weaning they were placed with the other control animals which were littermates of the experimental animals.

At the time of subdivision into the three control groups the whole group was so divided that approximately the same number of littermate controls was placed in each subgroup; likewise, the same number of non-littermate controls was placed in each subgroup. The total number of animals that finished the experiment in each of the four groups (C_1, C_2, C_3, and E [the experimentals]) was forty-five.

The sex distribution in the groups was as follows: in each of the three control groups there were twenty-two males and twenty-three females; in the experimental group there were sixteen males and twenty-nine females.

d. *Maintenance of Groups Prior to the Learning Experiments.* In order that the desired difference in growth rates of the experimental and control animals might be brought about, the experimentals were kept separated from the mother for varying lengths of time each day, the exact length of time varying somewhat from litter to litter and from individual to individual according to weight and physical condition (judged by color of skin, vigor, and amount of milk apparent in the stomach). After the young had been weighed and divided into the two groups approximately twenty-four hours after birth, the experimentals were separated from their mother and littermate controls. In general, the procedure was to keep the experimentals from the mother for eight hours and then to place them with the mother and the controls, or to place the mother with them, for approximately four hours. This nursing period was followed by another eight-hour deprivation period which in turn was followed by a four-hour feeding period. After one or two repetitions of this procedure, the young were placed on a schedule that permitted from two to three hours of nursing for the experimentals both in the morning

and in the evening of each day. The controls were with the mother in most cases at all times; however, there were times during nursing periods for the experimentals when only these animals were with the mother. Beyond the eighteenth or nineteenth day, when the condition of the experimental animals so warranted, the lengths of the nursing periods were somewhat shortened. Whenever an animal appeared to be gaining so little as to endanger life, as judged from previous experience of the experimenter, it was allowed to nurse an extra hour or two, hence there were many deviations from the foregoing general plan of procedure.

From the time the animals were weaned, at twenty-five days of age, they were reared in the hardware cloth cages. The controls were given all of the moist food and water that they desired until the thirtieth day. The experimentals were fed only a small amount of moist food twice daily until thirty days of age.

The food used throughout this experiment for the young and for lactating mothers was the Steenbock mixture. Half a leaf of lettuce per animal was supplied once a week; this amount would be roughly about 70 sq. cm. per animal.

5. Motivation: Maintenance of Groups During the Learning Experiments

Not knowing in advance what the results of the learning experiments might be, it was advisable to consider the possibility that the experimental group might display no deleterious effects as far as learning was concerned. In fact, because of their intense hunger these animals might be motivated to greater effort than controls trained under conditions of motivation currently used in laboratory experiments and, because of this heightened motivation, might actually exceed the controls in performance. To meet this possibility, the experimenter used three control groups that had been reared normally from birth to the time of the formal learning tests and thereafter so deprived as to provide stronger motivation than is ordinarily used with controls, if this could be done by very severe restrictions of

rations.   This division of the controls was made when the animals were thirty-six days of age and just after their training on the straightaway.

For the Warden U-maze, animals of Group C_1 were allowed to eat enough food daily at the end of their second trials to increase their body weights on an average of approximately 0.75 gram per day.   This provides for strong motivation in young animals, yet it allows for a slow rate of growth.   The weights of all animals in Group C_2 were held at maintenance from the age of thirty-six days to fifty-five days (the duration of the trial series on the Warden maze).   The animals of Group C_3 were reduced in weight as much as possible, but were still kept active for maze running.   Those in the experimental group (Group E) were held at as low a weight as possible, but a weight which would allow the animals to be active for maze running.

During a five-day interval after finishing the Warden U-maze, all of the animals were fed the standard diet in dry form, and water was present in the cages at all times.   The animals of Group C_1 were fed *ad libitum*; those of Groups C_2 and C_3 were fed appropriate amounts to increase their weights but slightly; those of Group E were fed only enough to hold their body weights at maintenance or to increase very slightly.   This five-day pause in maze running was introduced to acquaint the animals with the dry diet which was to be used during the next trial series.   It was also used as a period for increasing the strength of the animals to some extent so that they could better endure the water deprivation.

While in training on the multiple-T maze all of the animals were deprived of water except at the end of each day's trial, when they were allowed a ten-minute drinking period.   No food was given during a one hour period following the maze trial.   This relatively long period was interspersed between the maze running and the feeding period in order to insure that the food itself would have little or no reward value in motivating maze training.   That this period is ample for accomplishing this purpose has been well demonstrated (11), (46).

Animals of Group C_1 were given food *ad libitum*, except during

the one hour period mentioned above. Since they were sub-jected to liquid deprivation, however, it is possible that they could have eaten more of the dry food if more water had been available. As it was, they ate of the food off and on at various times during the day. One hour after its maze trials, Group C_2 was given a quantity of food sufficient to last for several hours. If any food remained in the containers eight to twelve hours before the next day's maze running time, it was removed. This means that Group C_2 entered the maze situation each day with-out having had food for approximately eight to twelve hours. Animals in Group C_3 were given just enough dry food to main-tain their body weight. This amount of food was generally eaten in a short time after being placed in their cages. Group C_3, therefore, entered the same maze situation without having had food for approximately 21 to 22 hours. Group E was treated in the same manner as Group C_3.

The differential motivation of the controls, based upon differ-ent degrees of food deprivation, which was used in the two learn-ing situations as described above, was brought about in the ani-mals after the period of rapid structural development of the nervous system had taken place. Two important factors with respect to this differential motivation must be kept in mind: (1) since the weight reduction was brought about after the period of rapid development of the nervous system, little or no damage was done to the nervous system; (2) a group of control animals was obtained which, as nearly as possible, approximated the intraorganic bodily state of Group E. In comparing the four groups of animals, one with the other, these two factors are important in interpreting adequately the results and in sepa-rating the effects of inanition from whatever influence the motivational factor alone might have had upon the performance of Group E.

III. GROWTH RATES

The differences in growth between the animals in the control and the experimental groups throughout the course of the ex-periment can be seen in the weight curves presented in Figure 2.

From birth until thirty days of age the two curves represent the daily weights of (1) the experimental group and (2) the control group[8] before any weight reduction had been brought about for the purposes of motivation.   The mean weights for the control and the experimental groups, respectively, on the thirtieth day are 59.40 and 20.13 grams.   In Figure 3, *A* are shown two litter-
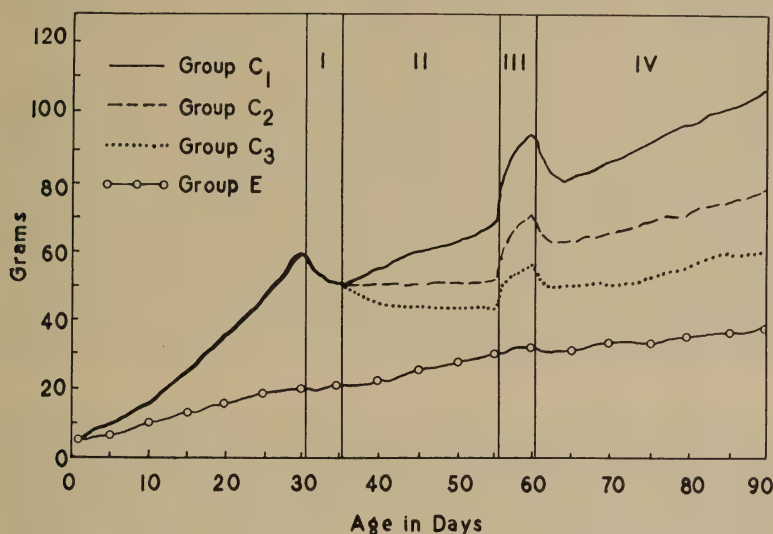
Fig. 2. Growth Curves for the Experimental and Control
Groups of Animals

The curves show the progressive changes in average weights of the groups throughout the experiment.   The curve for the control group between days 1 and 25 represents the average weights for the littermate controls only.   On the twenty-sixth day and thereafter the averages include the weights of the non-littermate controls.   The averages include the weights of only those animals that finished the experiment.   The weights of all the control animals were reduced after the thirtieth day in order to provide motivation.   The periods indicated between the vertical lines are: I, straightaway training; II, training on the Warden U-maze; III, five-day period between the training on the two mazes; IV, training on the Stone multiple-T maze.   The diets during these periods are described in the text.

mates at thirty days of age, one in the control group and the other in the experimental group.   The extreme difference in size can plainly be seen.

[8] The weights of the non-littermate controls are included in the averages plotted here beginning on the twenty-sixth day.   These animals were not weighed prior to that time.

In Figure 2 (*I*) can be seen the change in the curve for the control animals resulting from the weight reduction brought
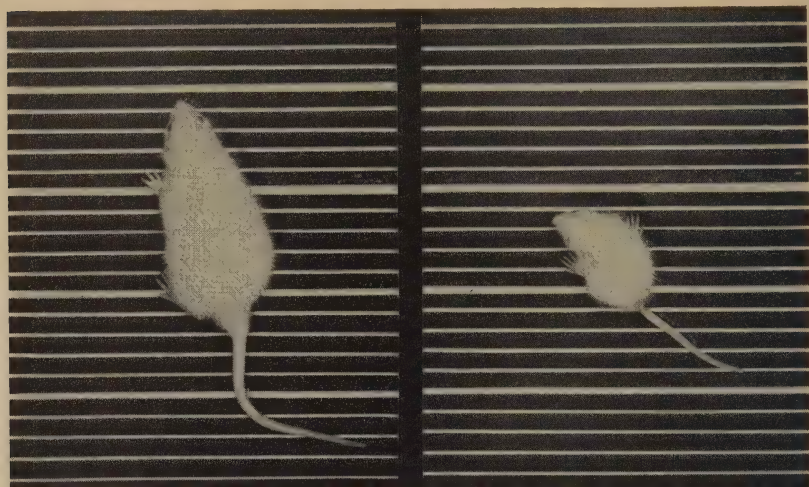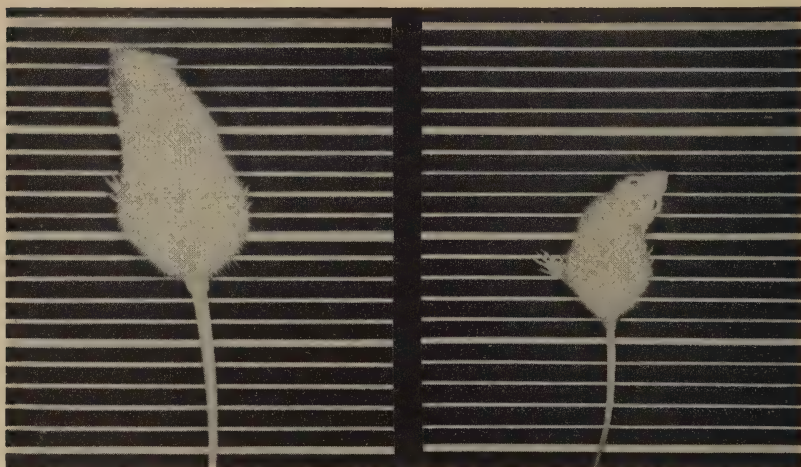
Fig. 3. Littermates: Control and Experimental Animals
White lines are 1 cm. apart

about during the training on the straightaway. Following this preliminary training, after the subdivision of the control group,

the curves of the three control groups can be seen to separate as the weights were controlled for the purposes of motivation as described in the section on Technique.   In Figure 3, *B* are shown two littermates at fifty-five days of age, one being a control animal in Group C_1 and the other an animal in Group E. The large difference in size between the two animals is striking.

The number of animals that died during the various phases of the experiment is listed in Table 1.   This analysis shows that most of the experimental animals failing to survive, died between

TABLE 1

Distribution of ages at which animals died during the experiment

DAYS OLD	PHASE OF THE EXPERIMENT	CONTROLS (DAYS 1–30 IN-CLUDE LITTERMATES ONLY)	EXPERIMENTALS
1–10	Developmental	None	12
11–20	Developmental	1	25
21–30	Developmental	None	5
31–35	Straightaway	None	1
36–55	Warden U-maze	2 (in Group C_3)*	2
56–60	5-day controlled refeeding	None	3
61–90	Stone multiple-T maze	1 (in Group C_2)	
		3 (in Group C_3)	0†

* Two other animals in Group C_3 did not die but were removed from the group, because they became very weak and had to miss several days of maze running.

† One animal was removed from the experiment during this time because it developed an ear infection which noticeably disturbed the animal's maintenance of equilibrium.   The data for this animal are not included in the calculations.

the eleventh and twentieth days.   Although not shown in the table, the majority of these twenty-five deaths occurred between the tenth and fifteenth days.   Forty-two per cent of the animals placed in Group E at birth finished the experiment.

A possibility exists that only the hardy animals were able to survive the severe inanition and if a positive relationship should exist between hardiness and maze performance, a selective factor might be present which would make the average learning scores for Group E superior to what they would have been if all animals had survived and had undergone maze training.   To the author's knowledge, no one has demonstrated a positive relation-

ship of this kind and the only evidence found which bears on this point indicates that no relationship is present. Fritz (10) found in his experiment dealing with malnutrition that the average error score on the day before death made by those experimental animals that died during the maze training was slightly better than (not significant) the average score based on the same trials for the malnourished animals that lived throughout the course of the experiment. Since the experimental diets were severe enough to cause death, and since one might reasonably expect the influence of the diets to be at a maximum on the day previous to death, no relationship must have been present between hardiness and maze performance. With the available evidence on this point being negative, then, this factor is not considered further in the interpretation of the results which follow.

IV. MAZE DATA

The basic data with which comparisons between the experimental and the control groups will be made consist of the error data and the time scores from the Warden U-maze and the Stone multiple-T maze.

1. Warden U-maze

Error curves based on the mean number of errors per trial for the experimental and the three control groups are presented in Figure 4. No gross differences are apparent in the general shapes of these curves. In Table 2 are given the means of the total number of errors made by each of the groups in the forty trials; Group E is shown to have the fewest errors, with Groups C_3, C_2, and C_1 following in the order listed. In order to discover whether or not any of the differences between these means were statistically significant, the critical ratios of the differences given in Table 2 were calculated.[9] Table 2 is arranged to show the

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[9] In computing the standard error of the difference between two groups, the correlation of the two groups in the variable being studied should be taken into consideration. Since a number of littermates were included among the four groups (all of the experimental animals had littermates in at least one of the control groups), this factor might conceivably be of importance. Burlingame and Stone (6), however, have found the littermate correlation in error scores

mean of each group in comparison with the mean of each of the other groups; it also gives the differences between means and the standard errors of the differences.   The critical ratios obtained by dividing the differences by the standard errors of the differences are recorded just below these other two numbers. Critical ratios of three or over are regarded as statistically significant.

From an analysis of the critical ratios in this table, it is concluded that the four groups of animals do not differ from each
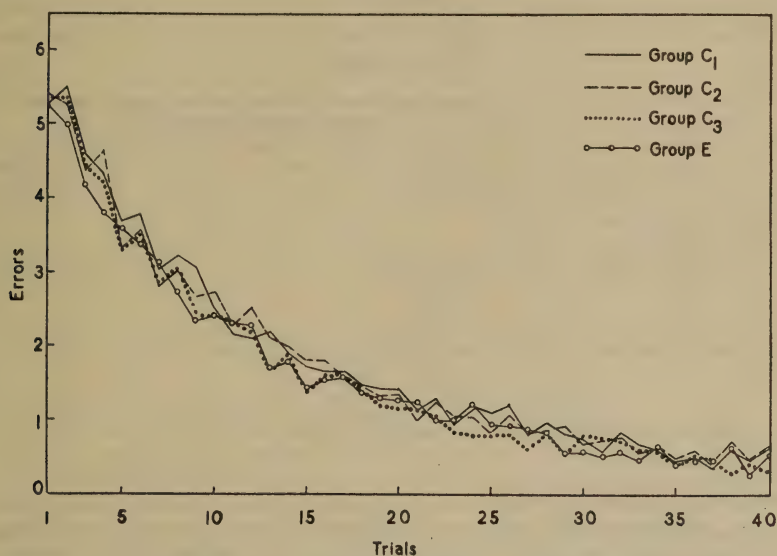
FIG. 4. MEANS OF ERRORS BY TRIALS.   WARDEN U-MAZE

other in their total error scores by more than an amount which chance would allow in a large percentage of cases.   In the case of Group C_1, the amount of weight reduction used for the purpose of motivation was so small that little or no retardation in growth of the nervous system of these animals would be caused

to be in the vicinity of +.31.   Since a correlation factor of this size would tend to raise the critical ratios only slightly, it is disregarded throughout the calculations.   It would also have been difficult to apply this correlation correction factor, because only about one-third of the animals in any of the control groups were littermates of the experimental group, and there was a varying number of other littermates ('additional control animals') among the control groups.

(15). Group C_2 was reduced in weight to a greater extent than was group C_1, and Group C_3 was in turn reduced in weight to a greater extent than was Group C_2. These last two groups performed even a little better than did Group C_1. Since no significant differences in performance appear in the error scores of these three control groups, even though hunger deprivation was carried to the extreme in the case of Group C_3, these groups must all have been performing with the highest degree of effi-

TABLE 2

Comparisons between the means of the total number of errors for the four groups.
Warden U-maze

GROUP	MEAN	S.D.	σM	DIFFERENCES BETWEEN GROUP MEANS, THEIR STANDARD ERRORS AND CRITICAL RATIOS			
				Group C_1	Group C_2	Group C_3	Group E
C_1	72.53	31.64	4.72				
C_2	71.80	26.72	3.98	-0.73 ± 6.17* -0.12†			
C_3	66.33	16.28	2.43	-6.20 ± 5.31 -1.17	-5.47 ± 4.66 -1.17		
E	66.20	25.32	3.77	-6.33 ± 6.04 -1.05	-5.60 ± 5.48 -1.02	-0.13 ± 4.48 -0.03	

* The signs before each difference and critical ratio indicate which of the group means is the larger. A plus sign indicates that the group mean belonging to that row is larger than that belonging to the group indicated by the letter in that column. A minus sign indicates that the opposite is true.

† The critical ratio is presented in the line just below the difference and the standard error of the difference.

ciency. Since this is true and since Group E performed in an insignificantly different manner from Group C_1 and the other control groups, one can find no evidence of a deleterious effect of early inanition upon the maze learning of Group E, as measured by the total error scores on the Warden U-maze.

An analysis of the error scores of the four groups was made to find the median number of trials required by each group to reach (but not to include) a criterion of three errorless runs out of four

consecutive trials.   The relevant data are given in Table 3. Since some of the animals were not able to satisfy the criterion in the forty trials given, medians rather than means were calculated for each group.   The quartile deviation for each distribution is given in the second column of this table.   The Q was converted into the standard error of the median and critical ratios were then calculated for the differences between the medians.   All critical ratios indicate that no significant differences were present between the groups.   The data here again indicate, as in the case of the means of the total number of errors, that

TABLE 3

Median number of trials required by each group to reach a criterion of mastery of three errorless runs out of four consecutive trials.   Warden U-maze

GROUP	MEDIAN	Q	σMdn.	DIFFERENCES BETWEEN GROUP MEDIANS, THEIR STANDARD ERRORS AND CRITICAL RATIOS			
				Group C_1	Group C_2	Group C_3	Group E
C_1	26.75	9.32	2.57				
C_2	27.75	8.72	2.41	+1.00 ±3.52 +0.28			
C_3	23.88	8.63	2.38	−2.87 ±2.50 −1.15	−3.87 ±3.39 −1.14		
E	25.17	8.17	2.26	−1.58 ±2.42 −0.65	−2.58 ±3.30 −0.78	+1.29 ±3.28 +0.39	

even the control group least reduced in weight was performing at approximately as high a level of efficiency as was the control group most reduced in weight.   This is interpreted as meaning that the groups were performing at a maximum level since no better motivation could have been produced by further weight reduction.   As measured by trials to reach a criterion of mastery, Group E, the group severely undernourished from birth, performed approximately the same as C_3, the most deprived of the control groups.   Since this is true, no significant inferiority in maze learning is found in the case of Group E in comparison with the controls.

The curves for the average time by trials for each of the four
groups are presented in Figure 5. They indicate that the ani-
mals in Group C_1 were slower than those of the other groups
throughout the trials. Group C_2 animals were next slowest,
and those of Groups C_3 and E were the fastest and performed
about the same.

The saw-toothed curve of Group C_1 arises from the fact that
the animals ran faster on the second trial of each day than on
the first. Since this dentate pattern is less marked in the curve
for Group C_2 and practically absent from the curves of Groups
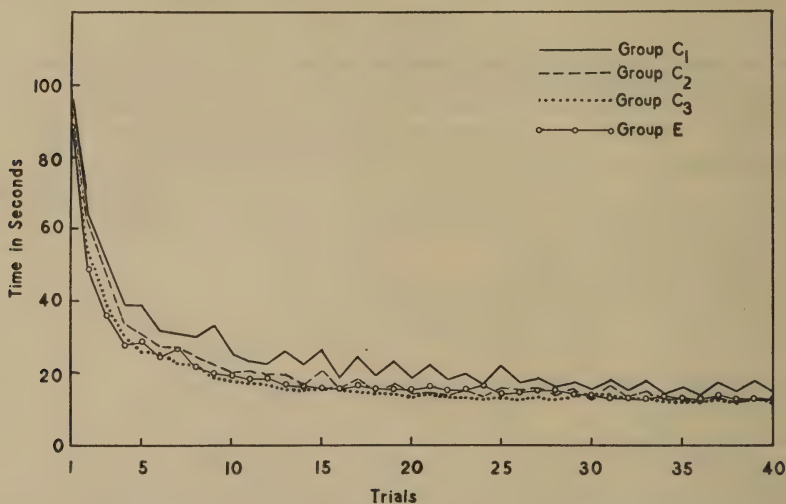
FIG. 5. MEANS OF THE TIMES BY TRIALS. WARDEN U-MAZE

C_3 and E, one may infer that the more intense hunger motiva-
tion of the latter two groups has eliminated the differences in
speed of running occurring between the first and second trials
on each day. It has also produced faster running in general.

The critical ratios of the differences between the means of
total time are recorded in Table 4. Groups C_2, C_3, and E have
lower means than Group C_1. Only two differences, those be-
tween C_3 and C_1 and between E and C_1, however, are signifi-
cant. This would indicate that in the case of the former com-
parison the differences in amount of weight reduction between
these two groups has produced a real difference in the mean

times for traversing the maze, those animals most reduced in weight running the faster. This more rapid running by Group C_3 is attributed to an increase in motivation. The significant difference in the case of the comparison between Groups E and C_1 is likewise attributed to a higher motivation in the case of Group E. The differences between Groups C_2 and C_1, C_3 and C_2, E and C_2, although not being significant, point in the same direction.

TABLE 4

Comparisons between the means of the total time scores for the four groups.
Warden U-maze

GROUP	MEAN	S.D.	σM	DIFFERENCES BETWEEN GROUP MEANS, THEIR STANDARD ERRORS AND CRITICAL RATIOS			
				Group C_1	Group C_2	Group C_3	Group E
C_1	1017.80	391.17	58.31				
C_2	856.29	254.37	37.92	-161.51 ± 69.56 -2.32			
C_3	761.16	121.40	18.10	-256.64 ± 61.05 -4.20	-95.13 ± 42.02 -2.26		
E	794.60	129.52	19.31	-223.20 ± 61.42 -3.63	-61.69 ± 42.55 -1.45	$+33.44 \pm 26.47$ $+1.26$	

The difference between Groups C_3 and E is not significant; this indicates that the group undernourished from birth performed approximately the same as did the best performing control group and no evidence is present, therefore, for any deleterious effects of inanition upon the performance of Group E as measured by time scores.

2. Stone Multiple-T Maze[10]

In Figure 6 are shown the curves for the means of errors of Type I by trials for the four groups. In general, one would say

[10] Errors of Type II were recorded and comparisons made between the groups. Since, however, errors of this type tend to be eliminated in the first five to ten trials and since no differences were noted between the groups, the data are not reported here.

that these curves are similar in shape but that in most of the
trials the curve for Group C_1 is a little higher (inferior) than the
others.   Although the curve of Group C_2 overlaps slightly with
that of C_1 during the first fourth of the trials, during most of
them the curves of Groups C_2, C_3, and E are similar and overlap
considerably.
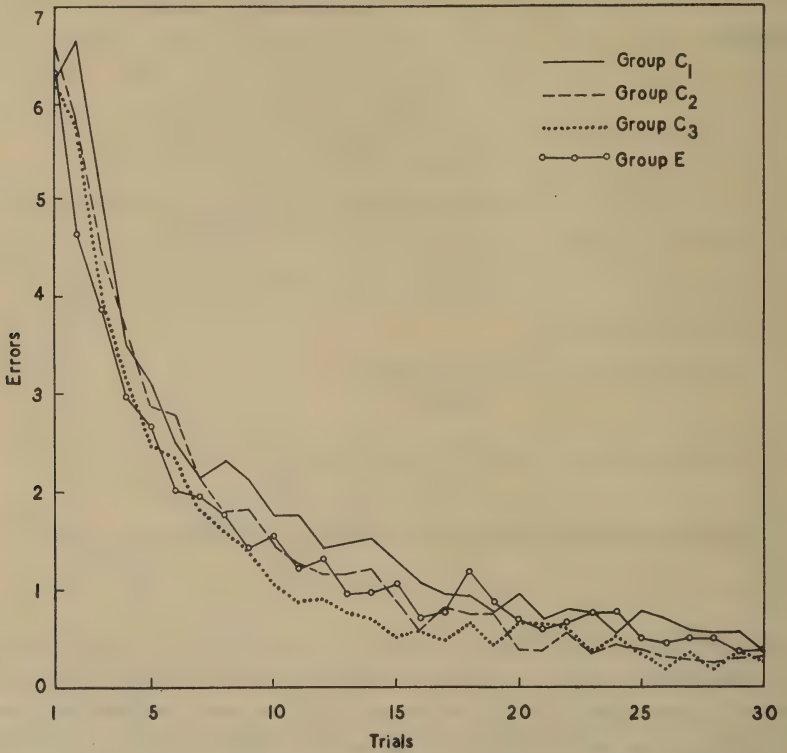
FIG. 6. MEANS BY TRIALS FOR FORWARD-GOING ERRORS.   STONE
MULTIPLE-T MAZE

Upon examining the means of the total number of errors for
the four groups presented in Table 5 one finds more regularity
in the data.   The means for the three control groups decrease
as the amount of food deprivation in the combined drive is
increased.   The mean for the group undernourished from birth
falls between those for Groups C_2 and C_3.   The critical ratios of
the differences shown in Table 5 are the largest when the two

best (a priori) motivated groups (C$_3$ and E) are each compared with the poorest motivated group (C$_1$).   Any superiority which Groups C$_3$ and E have over Groups C$_1$ and C$_2$ is undoubtedly

TABLE 5

Comparisons between the means of the total number of errors for the four groups.
Stone multiple-T maze

GROUP	MEAN	S.D.	σM	DIFFERENCES BETWEEN GROUP MEANS, THEIR STANDARD ERRORS AND CRITICAL RATIOS			
				Group C$_1$	Group C$_2$	Group C$_3$	Group E
C$_1$	54.04	24.87	3.71				
C$_2$	46.36	19.82	2.95	−7.68 ±4.74 −1.62			
C$_3$	40.60	17.16	2.56	−13.44 ±4.51 −2.98	−5.76 ±3.91 −1.47		
E	44.64	24.00	3.58	−9.40 ±5.16 −1.82	−1.72 ±4.64 −0.37	+4.04 ±4.51 +0.90	

TABLE 6

Median number of trials required by each group to reach a criterion of mastery of
three errorless runs out of four consecutive trials.   Stone multiple-T maze

GROUP	MEDIAN	Q	σMdn.	DIFFERENCES BETWEEN GROUP MEDIANS, THEIR STANDARD ERRORS AND CRITICAL RATIOS			
				Group C$_1$	Group C$_2$	Group C$_3$	Group E
C$_1$	17.50	9.97	2.75				
C$_2$	15.25	4.75	1.31	−2.25 ±2.05 −1.10			
C$_3$	13.08	4.04	1.12	−4.42 ±2.97 −1.49	−2.17 ±1.72 −1.26		
E	13.83	6.85	1.89	−3.67 ±3.34 −1.10	−1.42 ±2.30 −0.62	+0.75 ±2.20 +0.34	

due to motivation.   The means for Groups C$_3$ and E are the lowest and the critical ratio of the difference between these two means is not significant.   These data therefore provide no evi-

dence for any inferiority of Group E over highly-motivated control animals. The evidence does indicate, however, that a combination of hunger and thirst is better in promoting learning than is thirst alone. This is true even though only water is used as the incentive at the end of the maze. This agrees with the findings of Elliott (9).
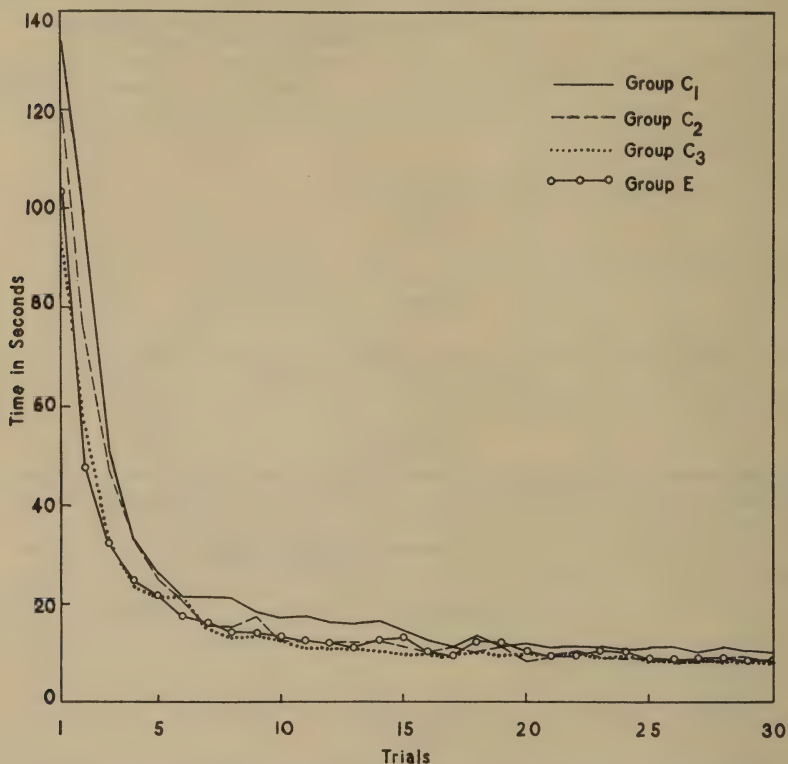
FIG. 7. MEANS OF THE TIMES BY TRIALS. STONE MULTIPLE-T MAZE

A comparison of the learning scores of the four groups was made on the basis of the number of trials required to reach a criterion of mastery of three errorless runs out of four consecutive trials. Those animals that had not reached the criterion within the thirty trials were given additional trials under the same conditions until a total of forty trials had been reached. Medians were calculated for each group rather than means,

because some of the animals were not able to satisfy the criterion by the fortieth trial.

The data for trials required to satisfy the criterion of mastery are presented in Table 6.   Groups C_3 and E reached the criterion in approximately the same number of trials; each of these groups was superior to Group C_2, and Group C_2 in turn was superior to Group C_1.   However, the critical ratios of the differences between the groups show that none of the differences is significantly greater than chance.   In the interpretation of these

TABLE 7

Comparisons between the means of the total time scores for the four groups.
Stone multiple-T maze

GROUP	MEAN	S.D.	σ_M	DIFFERENCES BETWEEN GROUP MEANS, THEIR STANDARD ERRORS AND CRITICAL RATIOS			
				Group C_1	Group C_2	Group C_3	Group E
C_1	706.47	269.19	40.13				
C_2	592.53	207.81	30.98	−113.94 ±50.70 −2.25			
C_3	497.69	130.01	19.38	−208.78 ±44.56 −4.69	−94.84 ±36.54 −2.60		
E	517.56	125.63	18.73	−188.91 ±44.29 −4.27	−74.97 ±36.20 −2.07	+19.87 ±26.95 +0.74	

scores one can find no evidence of impairment in the learning of Group E because the animals in this group performed approximately the same as the best motivated of the control groups.

In Figure 7 are presented curves for the average times by trials for the four groups.   These curves reveal small but fairly consistent differences.   Group C_1 is, in general, slower than the others; C_3 and E appear to be about the same and, in general, are the fastest.   The curve for Group C_2, although starting higher than those for Groups C_3 and E, coincides with them for the most part after the first ten trials.

The essential data for comparing the groups are presented in

Table 7. The differences between Groups C_1 and C_3, and between C_1 and E are statistically reliable. Group C_1 is the slower group in both cases. Although the differences between Groups C_1 and C_2, between Groups C_2 and C_3, and between Groups C_2 and E are not significant, the critical ratios of the differences between them are above two. These differences indicate that as the hunger (food deprivation) factor in the complex drive becomes greater, the speed of maze running increases. This trend of differences agrees with those found with the Warden U-maze where the speed of running also increased as the intensity of the food deprivation increased.

V. INTERPRETATIONS

In the interpretation of the results obtained in this experiment, the main problem is that of evaluating the differences found in maze learning, both statistically and with reference to the two variables, inanition and motivation. Inanition is the fundamental variable which the experiment was designed to investigate; motivation, as a variable between the control groups, was necessarily injected into the problem so that the effects of inanition upon the learning of the group of animals undernourished from birth could better be evaluated. The results from the learning data must be considered along with the motivation used in the experiment.

It has previously been found (39), (40), (18), (44) that with an increase in weight reduction (hunger motivation) there is a decrease in the error scores made in maze learning by white rats. In malnutritional studies in which rats or mice have been subjected to a severe quantitative deprivation of food soon after being weaned (2), (3), (30), (16) it has been found that the malnourished animals also performed better than the control animals. Even at such extreme levels of undernourishment the differences in maze performance between the control and malnourished groups have best been explained in terms of motivational differences. Severe quantitative deprivation of food after the time of weaning therefore has no apparent detrimental effect upon maze learning. Results from the control groups in

the present experiment corroborate this conclusion. The most comparable data are those obtained from the Warden U-maze although those from the Stone multiple-T maze also support the findings of the other experimenters. Group C_3 did not do more poorly on the two mazes than the least undernourished group, Group C_1. Group C_3 did approximately the same as, or slightly better than Group C_1 in mean error score and trials to reach a criterion of mastery on the Warden U-maze (differences not significant, however); it was superior (CR = 4.20) in mean time scores on this maze and was superior in both errors (CR = 2.98) and time (CR = 4.69) on the Stone multiple-T maze. Thus the evidence indicates that the animals subjected to severe inanition after being weaned were not injured in such a manner as to detrimentally affect their maze learning. The performance of the animals in Group C_2 was likewise not detrimentally affected by the amount of undernourishment to which they were subjected. Since the animals of Group C_3 were reduced in weight as much as possible, it would seem that no better maze performance (as measured by error, trial, and time scores) could be obtained by using further weight reduction as motivation.

In analyzing the performances of the animals in Group E in order to find the effects of the early inanition upon their maze performance, one must make comparisons between Group E and all of the other groups. When this is done for the scores on the Warden U-maze, Group E is found to have performed approximately the same in all the measures as Group C_3. With respect to total errors and the median number of trials to reach a criterion of mastery, the scores for all four of the groups are quite similar. With respect to the total time scores, Group E performed better than Groups C_1 and C_2 and performed approximately the same as Group C_3.

From these comparisons on the Warden U-maze the best conclusion one can draw is that as a result of inanition no injury has been brought about in the animals in Group E which has affected their maze learning so as to make them inferior to the control animals.

On the Stone multiple-T maze, Group C_1 was deprived only of water, whereas the other groups were deprived of water plus various amounts of food. The results from the control groups show that as the food deprivation became more severe the performance improved, both in errors and in time, even though water was the only incentive present at the end of the maze. The animals of Group E performed better than those of Groups C_1 and C_2, and did approximately the same as those of the more highly motivated Group C_3. Since they were not inferior, the indications again are that no impairment in maze learning has been produced in these animals as a result of inanition from birth.

A possibility that the difference in the number of males and females in Group E might have affected the results of the learning experiment must be considered. The results from experiments on sex differences in maze learning in rats (12), (31), (32), (7), (43), (19) differ somewhat not only as to the amount of superiority of one or the other sex but as to the direction of the difference. After a careful scrutiny of these studies, however, one finds that either male superiority or no significant sex difference is the most probable relationship. In the present experiment then, if no sex difference in learning is the case, the difference in number of males and females in Group E can be disregarded. If male superiority is the case, the fact that Group E had a majority of females would tend to make the scores for this group a little inferior to what they would have been had the sex ratio in the group been more nearly equal as it was in the case of the three control groups. Since the maze performance of the animals in Group E is already at a level comparable to the best performing control group, this slight added superiority would, of course, not change the conclusions from the results. However, since the difference in number of each sex in Group E was not very large the amount of difference that this might possibly produce in the scores is small.

The main results of this experiment are based upon animals whose undernourishment was begun soon after birth. Considering the results of this experiment in addition to the results of

other quantitative nutritional experiments, the best interpretation is that the development of the ability to learn (as measured by the mazes used) has reached the same level in the malnourished as in the control rats and is maintained at a normal level, even though the undernourishment is severe. That the growth of the nervous system is exceedingly resistant to influences which affect general bodily growth has been amply demonstrated (15), (29); it continues its development affected to only a minor extent by these factors. This resistance when an animal is in a state of inanition holds not only for structure but also for the functioning of the nervous system as is indicated by the organism's ability to adapt itself to its environment and organize maze stimuli in such a manner as to produce improvement in maze performance. These findings indicate that the organism is so constructed that the nervous system has a tremendous margin of safety in its structural and functional organization. Other structures and their functioning can be severely influenced by inanition (15), but even though the nervous system shows some anatomical changes as a result of inanition, malfunctional changes as measured by maze learning in this experiment cannot be detected.

VI. SUMMARY AND CONCLUSIONS

1. *Problem.* In this study the experimenter investigated the effect of severe inanition upon maze learning in the albino rat when the conditions of inanition were imposed from birth.

2. *Summary of Technique.* Litters of albino rats were divided into two groups at birth. One group was allowed to develop normally with adequate nursing; the other (Group E) was allowed only sufficient nursing to maintain life. Normal non-littermate animals of the same age were added to the control group in order to provide sufficient animals for a later subdivision of this group. After five days of preliminary training on a straightaway maze with two trials per day and with food as the incentive, training of the normal and undernourished groups under similar conditions was begun on the Warden U-maze. The animals were trained on this maze when they were from

thirty-six to fifty-five days of age. The control group was divided into three subgroups with forty-five animals (twenty-three females and twenty-two males) in each, in order to control motivation adequately. Animals in Group C_1 were allowed to increase in weight approximately 0.75 gram per day; animals in Group C_2 were allowed to maintain their weights; animals in Group C_3 were allowed to lose as much weight as possible and still be active in maze training. Animals in Group E (N = 45; 29 females and 16 males) were allowed to increase slightly in weight from birth throughout the experiment. The littermates of Group E were divided equally among Groups C_1, C_2, and C_3. In order to secure a second and somewhat independent measure of learning under different types of motivation, the animals were trained from the sixty-first to the ninetieth day of life on the Stone multiple-T maze with water as the incentive. The same general weight relationships between the groups were maintained.

3. *Summary of Results.* The learning data for the two mazes agree quite closely and in general show Groups C_3 and E to perform about the same; these groups are superior to Group C_2 which in turn is superior to Group C_1. The only exception to this is in the case of trials to reach a criterion of mastery on the Warden U-maze where Group C_2 slightly exceeds Group C_1. In the case of the average error scores and trials to reach a criterion of mastery, none of the critical ratios of the differences between the four groups is significant, although the order described above is present. For the time scores, however, the critical ratios are in general larger. Those between Groups C_3 and C_1 and between Groups E and C_1 are significant and the rest are larger than in the comparisons based upon error and trial scores even though not significant.

Throughout all measures of learning for both mazes Groups C_3 and E perform approximately the same, and the critical ratios of the differences between their scores are always small. Their learning scores are consistently superior to the others even though the differences are not always significant.

4. *Conclusions.* (a) Inanition when begun in albino rats soon

after birth has no deleterious effect upon their learning ability as measured by error, trial, or time scores on either the Warden U-maze or the Stone multiple-T maze.

(b) Albino rats reared normally but subjected to severe weight reduction after reaching the age of thirty days show no loss in maze learning ability as measured by error, trial, or time scores on the above two mazes.

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The Solution of Multiple Choice Problems by Chimpanzees

KENNETH W. SPENCE

From Yale Laboratories of Primate Biology

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THE SOLUTION OF MULTIPLE CHOICE PROBLEMS BY CHIMPANZEES[1]

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CONTENTS

1

I. HISTORICAL INTRODUCTION

From the beginning of the more systematic attempts to study the behavior of animals there was a rapid development in the types of experimental devices and procedures employed. Thorndike's use of the problem or puzzle-box method (15), which is usually taken as marking the birth of this period, was followed quickly by the introduction and extensive use of the discrimination (19) and maze methods (13, 16). None of these procedures, however, provided a satisfactory means for studying the higher mental processes of animals, as their solution required only a simple sensory-motor association or adjustment on the part of the animal. The need of new methods of research for studying the ideational behavior of animals soon became apparent.

As one might have expected from the dominance of Darwin's theory at the time, there was widespread interest in the problem of the evolution of reasoning and ideation in the phylogenetic series, and a number of investigators soon turned their attention to the problem of its experimental investigation. These studies, the first publications of which appeared at the beginning of the second decade of the century, led to the devising of three new methods of behavioral research: the quadruple choice method of Hamilton (5, 6), the multiple choice method of Yerkes (20, 21, 22), and the delayed reaction methods of Carr and Hunter (4, 8).

Each of these investigators was primarily interested in studying ideational processes and attempted to devise a research instrument which would throw light upon them. Hamilton, a psychiatrist interested in applying the comparative method to the problems of psychopathology, designed his procedure in such

a manner as to provide observations on the various types of reaction tendencies exhibited by human and animal subjects in their attempts to adjust to the problem set them. Instead, however, of centering his attention on the adaptive aspects of the organism's adjustments to new situations, he concentrated on the non-adaptive activities or "errors" that it made. And, in order to insure an ample number of such reactions, he confronted his subjects with an insoluble problem. From analysis of the data obtained on a variety of mammalian forms ranging from man to the white rat, Hamilton was led to describe five different levels or types of reaction tendency, the highest of which, "the rational inference tendency," he believed to be ideational in nature. In so far, then, as subjects exhibit this highest type of reaction tendency, this method provides a means of studying rational and ideational processes. Hamilton's own data showed that the proportion of these reaction patterns decreased rapidly as one descended in the phylogenetic scale. While the monkeys were found to be next to the human subjects in the proportion of the "rational inference" type, only in the human adult subjects did this highest form predominate.

Hunter's delayed reaction method was likewise introduced as a means of studying ideational processes in animals. This test, which typically requires the subject to retain over a period of time the appropriate cue as to which of two or more alternative responses to make, has come to be regarded as a method of studying immediate memory in animals. It has continued to be used quite extensively since its introduction for the measurement of mnemonic capacities, a variety of problems, such as, the determination of phylogenetic differences in the ability to delay, the factors that influence the length of delay, and the nature of the representative factor or mechanism by which the animal is able to bridge the interval, being studied.

Yerkes' multiple choice method, like that of Hamilton, also had for its purpose the experimental detection of reactive tendencies and the study of their rôle in the attempted solution of certain problems involving spatial relations. In addition, it emphasized two further aspects: (1) the mode of solution of

certain problems involving spatial relationships, i.e., whether or not ideational processes were operative; and (2) the comparative determination of ideational capacities throughout the phyletic series by the presentation of a series of increasingly difficult problems in a strictly comparable experimental situation.

Yerkes' method involved giving the subject a series of trials in which he is presented with a group of identical visual stimulus objects (open compartments or small boxes) among which one, if responded to, yields success (goal-object). The number of such boxes in a group and their locus in the apparatus are variable. The problem confronting the subject is to learn the correct box, which is always defined in terms of its spatial relation to other members of the group, as, for example, the left-end box or the middle box.

The question of whether the solution of multiple choice problems is evidence for the operation of ideational or symbolic processes has been raised by a number of writers (7, 17, 18). As early as 1916, Hunter (7), in reviewing the investigations of Yerkes and his students, argued that no proof had been adduced that the problems set could be solved only by a perception of the appropriate relationship.[2] He further pointed out that the chief evidence for ideational behavior cited by Yerkes was not the solution of multiple choice problems as such, but in such accessory data as the sudden jump to solution in the learning

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[2] It is interesting to note that Hunter expresses the opinion that the multiple choice method is applicable only to the study of "reaction tendencies." Concerning these latter he states that, while Yerkes has not defined them, they are undoubtedly "position habits" which appear in the course of the animals' attack upon the problem. The chief contribution of Yerkes' and Hamilton's work, according to Hunter "lies in the intensive study of position (kinaesthetic) habits which all experimenters have noted but which no one has sufficiently analyzed" (7, p. 329). For some reason, Hamilton's contribution to this approach to the study of animal behavior has been more or less ignored. Actually, he was the first to emphasize and develop methods for analyzing the ineffective "attempts at solution" of animals, even suggesting the statistical criterion which was later developed and refined by Krechevsky (9) in his work on discrimination learning. Various different names have been given to these pre-solution behavior patterns, such as "reaction tendencies" (Hamilton), "modes of adjustment" or "systematizations" (Yerkes), "hypotheses" (Krechevsky), or plain "position habits" (Hunter).

curves. Thus Yerkes contrasted the sharp difference, in this respect, in the solution of the simple problem, left-end box, by an orang-utan and various lower animals, and drew the conclusion that, whereas the latter had learned by trial and error processes, the orang had exhibited ideational behavior. Hunter, however, questioned the significance of this difference, pointing out that the sudden shift in response to the correct one is not remarkable, for the phenomenon of "varying means" is found in all animals and the speed of shifting seems to be merely a function of the urgency of the need.[3]

Another fact emphasized by Yerkes as evidence of the ideational character of the anthropoid's solution was its subsequent perfect response to a control series consisting of new orders and groups of stimulus boxes. However, the significance of this evidence has also been questioned. Warden, Jenkins, and Warner (17, p. 413) have attempted to show how the success of the ape in this control series can be explained in terms of mastery of the individual settings. While their analysis of the learning of the orang may be shown to be incorrect,[4] it is true, nevertheless, as these writers point out, that the control series consisted of settings which the subject had previously learned and hence was not critical. More recently, however, Yerkes (24) has shown that the solution of the left-end problem of chimpanzees was followed by 100 per cent correct response on a control series of new settings.

That such end-box problems probably do not involve ideation

[3] In this connection, the present writer has recently shown that sudden jumps to solution in the discrimination learning curves of chimpanzees need not be interpreted as involving any ideational or insightful processes not present in more gradually achieved solutions (12). Both types of curves were shown to be definitely correlated with associative changes resulting from selective training, thus rendering unnecessary the postulate of some different (ideational) factor, at least, in sudden discrimination learning.

[4] The orang did not exhibit, as they claimed, a preference for the left-most box from the beginning, but began with a tendency to choose the nearest box to it as it approached from the center of the apparatus. If the setting consisted of boxes to the left of center, it would choose the nearest, and hence right-end box; if the setting consisted of a middle group of boxes, it chose usually one of the middle boxes; while in the case of settings consisting of boxes to the right of center, it chose the nearest, and in this instance, left-end box.

at all, but only the learning of a position or kinaesthetic habit of turning to the left or right, has been the claim of other writers, among them Washburn (18). The latter is inclined to admit only the middle-box problem, of all those used by Yerkes and his co-workers, as requiring ideation. Strong support may be found for the view that the end-box problem requires only the learning of a simple position habit in the data presented in table 1. It will be seen that there is little or no relationship between speed of learning, or the control series performance, and position in the phyletic series. Much more important in determining the rate of learning is the response habit or prefer-

TABLE 1

Showing comparative data for different animals on "end-box" multiple choice problem

SUBJECTS	NUMBER	TRIALS TO LEARN		CONTROL SERIES	
		Mean	Range	Mean	Range
				per cent	*per cent*
Chimpanzee..................	4	270	180–410	100	—
Monkey.......................	2	115	80–150	77	60–85
Orang-utan...................	1	300	—	100	—
Pig..........................	2	50	45–55	100	—
White rat....................	4	222	170–350	93	80–100
Cat*........................	1	470	—	90	—
Crow........................	2	53	50–56	—	—

* Unpublished data kindly made available to the writer by Dr. Donald K. Adams of Duke University.

ence the animal brings to the situation. Thus the markedly slow learning of the chimpanzees in Yerkes' most recent study (24) was due to a strong preference for boxes to the right side of the apparatus (opposite to the correct box) resulting from the asymmetrical position of the goal box on the right side.

When we turn to the level of attainment in terms of complexity of the problems solved by the various animals we again fail to find any significant correlations with phylogenetic position. Only one subject, a European siskin (11), has been reported able to solve the middle-door problem. Four chimpanzees (24) failed in this problem, as did one monkey (20) and two pigs (25).

The problem next in difficulty, the alternate-end-door, was successfully solved by two pigs (25), one of two monkeys (20), and one only of four chimpanzees. Likewise, only one chimpanzee of four was able to succeed with the second-door-from-end problem (24). This latter was also solved by three monkeys (20, 14), two pigs, a skunk (10), and a marten (10). It proved too difficult for the orang-utan (20) and two white rats (2). All subjects tested, chimpanzee, orang, monkey, pig, cat, white rat, and crow, have been reported as succeeding with the simple end-box problem.

It is readily apparent from the above survey that the main difficulty with the multiple choice method as a means for studying and comparing the nature of the adaptational process in animals is that it has so far presented too difficult problems. Unfortunately, when simpler problems have been used, there has been considerable doubt as to whether their solution has involved a perception of the spatial relationship. In the introduction to his most recent study with chimpanzees (24), Yerkes indicated that he appreciated this fact, but continued to use the problems which had previously been presented to crows, pigs, monkeys, etc., in order not to sacrifice comparability of results. At the same time he suggested that the present writer undertake a parallel investigation, in which no attempt be made to preserve the traditional multiple choice procedure and apparatus, but instead attention be directed to discovery of modifications which might widen its usefulness and enhance its value.

With this methodological objective as a background, an investigation was undertaken, the chief behavioral interest of which was the study of the nature of the adaptational process in chimpanzee to problem situations which involved the perception of spatial relationships. The particular problems investigated were: (1) the nature, if any, of the systematic reaction tendencies exhibited in the pre-solution period; (2) the analysis of the basis of the solution, i.e., whether or not it is based on the perception of the essential relationship; (3) factors determining the rate of adaptation, such as, previous experimental experience, age of subjects, number and spatial distribution of settings, etc.; (4)

transfer effects (positive and negative) of successive problem solutions.

II. APPARATUS AND PROCEDURE

Two main differences distinguish the apparatus and procedure employed in the present study from those used in previous investigations. One of these differences consisted in the fact that a manual type of multiple choice apparatus was used instead of the large compartment type, and the second, in the fact that, in any one of the problems presented the animals, the number of boxes in the various settings was always kept constant.

Apparatus

The manual form of apparatus used (described by Yerkes, 23, pp. 120–122) was a modification of that designed by Bingham for chimpanzees and used by him in an unpublished study of multiple choice reactions of children. As used in the present experiment, the apparatus is shown in figure 1; the upper part presents a front view, and the lower, the relation of the apparatus to the living cage and to the position of the experimenter. It consisted of eleven small, nickelplated brass boxes 6.4 x 7.6 x 7.6 cm., arranged (10.2 cm. apart) along a board or platform 180 cm. long and 15 cm. wide. The boxes were hinged to the back of the platform on the side away from the animal and could be opened easily by pushing against the front of each. The board or platform which carried the metal boxes was mounted on small ball-bearing wheels which ran in a track on a metal framework placed before the animal's living cage. By pushing the platform up to a position 1 inch from the cage wall, the animal was able to reach its finger through the 2-inch mesh wire fence, push open the boxes, and obtain the food. The boxes could then be withdrawn to a position 80 cm. from the cage wall of the animal and a sliding opaque screen dropped between them, thus permitting their reloading and resetting for the ensuing trial. The boxes not being used on any setting were thrown back from the platform, as appears in the illustration. In such a position they could not be mistaken by the animal as a possible source of reward.
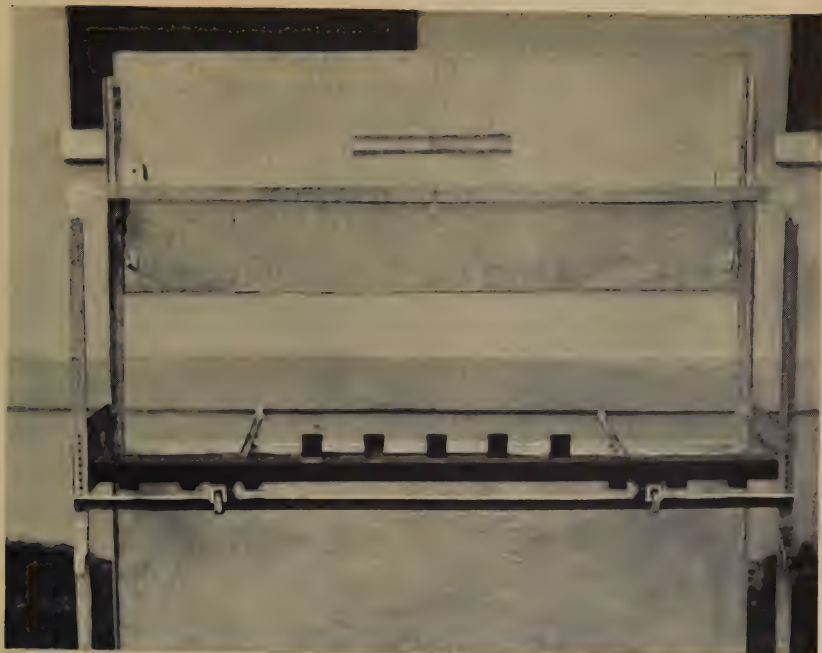
Fig. 1. Upper: Front View of Apparatus. Lower: Rear View of Apparatus

9

Young animals, easily handled, were worked in a large, indoor experimental cage (16 x 16 ft.) which contained a grilled opening of horizontal bars through which they could reach the boxes. The framework on which the apparatus was mounted was similar to that used with the larger animals, except that it was constructed of wood. The adult subjects were worked in one of the outside living cages of the Animal Quarters building, the metal apparatus being set up permanently at one side of the cage (see fig. 1, lower). The panels of the cage wall were about the same width as the apparatus so that no post interfered with response to any of the boxes.

The most important advantage that this manual type of apparatus has over the compartment type is that the small size of the boxes should make it easier for the animal to see the relation of the correct box to the others. This is particularly the case when an incorrect response is made on the first attempt. In addition, it possesses the practical advantages of speeding up the reactions of the animal and reducing the costs of construction.

Experimental procedure

Only very brief preliminary training was required to accustom the animals to approach, open the boxes, and obtain the lure. In most cases a single day sufficed, but for a few of the more timid animals, particularly the 2- and 3-year-old infants, several days were required before the appropriate response was made readily and with ease.

Following this preliminary adaptation, regular training was begun on the first problem. Only the general outline of the experimental procedure will be given here, leaving the particular details to each of the different problems. Working behind a screen, the experimenter arranged the appropriate boxes on the platform, placing food under the correct one, e.g., as in problem 1, under the middle box of five adjoining boxes. The remaining boxes were left unloaded and unlocked. The screen was then raised and the platform carrying the boxes pushed forward to a position where the animal could reach the boxes. If the animal responded correctly, i.e., opened the box which was

loaded for that particular problem, it obtained a small piece of banana or citrus fruit as reward. In the case of an incorrect response, the procedure varied from one problem to another and will be described for each separate problem. Following the completion of the response, the apparatus was immediately withdrawn behind the screen and the setting of boxes arranged for the next trial. The experimental work was carried out six days a week between the hours of 9:00 and 12:00 A.M., except for a few isolated interruptions which will be noted.

Outline of experimental problems

In some exploratory experiments, in which the arrangement of the apparatus was somewhat different from that finally used, two young subjects, Gua and Mamo, were presented with two problems: (1) the middle box of three adjoining boxes, (2) the second box from the right end, in which each setting consisted of six boxes. Thus the settings differed only in their spatial position, one setting consisting of boxes 2, 3, and 4, of which 3, being in the middle, was correct; another of boxes 4, 5, and 6, with 5 now the correct one, etc. It was thought and hoped that keeping the number of boxes in each setting constant instead of varying them might simplify the problem sufficiently to permit of more ready solution. This change does not alter the essential principle of the multiple choice method, the correct mechanism still being definable in terms of some definite spatial relation to other members of the group, such as, the middle box or second box from the right end.

Both subjects learned the problems fairly readily, the first problem in 60 and 140 trials, and the second in 310 and 350 trials. Moreover, both responded without error to a new order of settings, thus eliminating the possibility that the solution was based on the learning of the sequence of correct boxes. It was therefore decided to begin the regular experiment in a better controlled situation with this simplified type of problem involving a constant number of boxes in each setting. The problem selected was the middle box of five adjoining boxes. In addition to this middle-box problem, four further problems were presented

to varying numbers of the subjects. They were as follows: (2) the second box from the left end of settings of six boxes, (3) the right-end box of seven boxes, (4) the left-end box of seven boxes, and (5) relearning of the original middle-box problem.

TABLE 2

List of chimpanzee subjects

NAME	SEX	BIRTH DATE	LIMITS OF PERIOD OF WORK
Adults:			
Mona.....................	F	1913	10/ 2/34– 2/20/35
Pati......................	F	1920	10/ 2/34– 3/17/35
Josie.....................	F	1922	10/ 2/34– 3/ 8/35
Wendy....................	F	1923	10/ 2/34– 2/14/35
Mimi.....................	F	1923	1/15/35– 5/ 2/35
Lia.......................	F	1924	1/15/35– 5/21/35
May......................	F	1925	1/15/35– 5/30/35
Bokar....................	M	1925	6/ 7/34– 7/13/34
Nira.....................	F	1926	6/ 7/34– 7/17/34
Cuba.....................	F	Mar. 24, 1926*	6/ 7/34– 7/21/34
Adolescents:			
Bentia...................	F	1926	1/ 3/34– 4/30/34
Soda.....................	F	1927	1/ 3/34– 4/30/34
Al.......................	M	1927	1/ 3/34– 4/30/34
Mamo....................	F	1928	1/ 3/34– 4/30/34
Children:			
Tom......................	M	June 26, 1933*	5/13/35– 7/27/35
			10/12/36–11/30/36
Bob......................	M	June 27, 1933*	10/12/36–12/15/36
Dick.....................	M	July 15, 1933*	5/13/35– 7/28/35

* Actual birth date; all others hypothetical.

Subjects of experiment

Seventeen chimpanzees, ranging in age from 2 to 22 years, served as subjects in various parts of the experiment. Ten were sexually mature, four were adolescents, and three in early childhood. Table 2 lists the name, sex, date of birth, and limits of period of work for each subject. The three children were all born in the Florida division of these laboratories. Tom was the offspring of Mona, Bob of Wendy, and Dick of Josie; all three

mothers, it will be observed, were also subjects in the experiment. Each of the infants had had some previous experimental experience in a delayed reaction study.

The adolescents, Bentia, Mamo, Soda, and Al, were experienced subjects. Bentia became sexually mature as evidenced by the appearance of menstruation during the course of the investigation. Of the adult group, only Bokar and Wendy were experienced experimental subjects. Both had been used in a variety of behavioral experiments in the New Haven division of the laboratories. Mimi and Lia had been used briefly in some preliminary discrimination experiments by the writer, while the remainder were more or less naïve so far as behavioral experimentation was concerned.

III. PROBLEM 1. MIDDLE BOX OF FIVE BOXES

Conditions during learning series

On each of the first 20 days (240 trials) of training in this problem the subjects were presented with a series of 12 trials, which consisted of 4 different settings given three times each. For thirteen of the seventeen subjects, these settings were made up of the following boxes: 1, 2, *3*, 4, 5; 3, 4, *5*, 6, 7; 5, 6, *7*, 8, 9; 7, 8, *9*, 10, 11; while in the case of four other subjects the 4 settings were boxes 2, 3, *4*, 5, 6; 4, 5, *6*, 7, 8; 6, 7, *8*, 9, 10; and 7, 8, *9*, 10, 11. During this period all of the subjects were permitted to keep opening the boxes, all of which were unlocked, until the correct one was hit upon and the food was obtained. Beginning on the 21st day of training (241st trial) this "correction" procedure was discontinued, the subject being permitted to open only a single box on any trial. If the response was incorrect, the apparatus was immediately withdrawn behind the screen so that there was no opportunity for further response. On the ensuing trial a new setting was presented. Also, beginning on the 21st day of training, two series of 12 trials were given each day, and beyond the 20th series (trial 960) four series were run daily. The orders of presentation of the settings, designated by the correct (middle) box of each, were as follows:

Learning Series A: 7 3 5 9 7 5 9 3 5 7 3 9
Learning Series B: 8 4 6 9 8 6 9 4 6 8 4 9

Learning trials were continued until the subject responded in all 12 trials of a series without error. The time taken by the subject from the raising of the screen until the obtaining of the food was recorded by stopwatch. At intervals throughout the training, special tests were made to control the possibility that the subjects were responding to the odor of the food under the correct box by placing food under all boxes and locking the incorrect boxes.

Conditions during control series

On the two days following the attainment of the learning criterion a special control series of 16 trials was given. This series consisted of 6 trials with the 4 settings of the regular learning series and 10 trials with 3 settings which had never been presented before, given in the following order:

Control Series A: 7 4 6 3 8 5 7 9 6 4 5 8 6 8 4 6
Control Series B: 8 3 5 4 7 6 8 9 5 3 6 7 5 7 3 5

The experimental conditions during these control series were identical with those in the latter part of the learning series, the subject not being permitted to correct. Ten of the animals were also given two special control series of 10 trials in which 5 settings consisting of 7 boxes were employed. In this test the subjects were permitted to continue opening the boxes until successful. One subject (Bentia) was also tested with settings of 9 boxes.

Experimental results and discussion

A. Learning and control series data. In contrast to the consistent failures of solution of the middle-box problem in previous investigations, all but two of the seventeen subjects succeeded in learning this modified middle-box problem in the manual multiple choice apparatus to the criterion of 12 successive correct trials. The two subjects that failed to meet this rigid criterion undoubtedly would have succeeded if given further training. One of them, Al, was discontinued after 504 trials because his occasional errors seemed to be more a matter of lack of motor

precision than failure to understand the problem. Dick, a 2-year-old infant, stopped working at the end of 240 trials. He had been doing splendidly, making only one error on two different series, when he suddenly began to make a succession of errors. It was only with difficulty that he was induced to complete the series, and thereafter he refused to work in the experiment despite

TABLE 3

Showing the number of trials and errors required for learning problem 1 and the percentage of correct responses in the control tests

SUBJECTS	AGE	LEARNING DATA			CONTROL DATA		
		Difficult criterion Trials	Easy criterion Trials	No. of errors	1st test	2nd test	Mean 1 and 2
					per cent	per cent	per cent
Mona..........................	21	1080	1068	626	40	20	30
Pati..........................	14	1416	1416	862	0	0	0
Josie.........................	12	1068	876	564	50	50	50
Wendy.........................	11	588	588	389	80	80	80
Mimi..........................	11	888	564	418	20	50	35
Lia...........................	10	852	792	455	50	30	40
May...........................	9	960	672	449	30	40	35
Bokar.........................	9	456	456	249	50	60	55
Nira..........................	8	516	516	295	70	90	80
Cuba..........................	8	588	516	275	30	60	45
Bentia........................	8	408	408	255	100	100	100
Soda..........................	7	456	456	255	70	100	85
Al............................	7	—	432	—	80	40	60
Mamo..........................	6	336	300	141	90	90	90
Tom...........................	2 and 3¼	396	324	273	60	40	50
Bob...........................	3¼	828	828	489	60	40	50
Dick..........................	2	—	216	—	—	—	—

every effort to get him to do so. Both of these subjects satisfied the less rigid criterion of 20 correct trials out of 24 trials.

Table 3 presents the learning data and control series results for all subjects. Three measures of learning have been used: (1) the number of trials to attain an errorless series, (2) the number of trials necessary to reach the criterion 20 out of 24 trials, and (3) the number of errors made in meeting the more

rigid criterion.[5] It will be observed from the table that the range of learning scores is fairly large, the smallest number of trials (rigid criterion) being 336 and the largest 1416, the smallest number of errors 141 and the largest 862.

B. Age, experience, and learning. One question that interested us was whether there would be any relationship between age and the capacity to solve multiple choice problems. Would infant chimpanzees be able to learn such problems, and if they were, how would their performance compare with that of adults? The results of table 3, it will be seen, exhibit a marked tendency for speed of adaptation to be inversely related to age, for it will be observed that the older subjects, in the top half of the table, in general took longer to learn than the younger, immature animals in the lower half. However, these data are complicated to a considerable extent by other factors, particularly differences in the amount of previous experimental experience of the subjects. Thus four of the younger group, Bentia, Soda, Al, and Mamo, were the same subjects that Yerkes used in his multiple choice experiments (24). Mamo had also had previous experience in the present apparatus and had learned a very similar problem, the middle box of three. Further evidence that experimentally sophisticated subjects learn more quickly appears in the data of the adult group. Thus, the mean number of trials to learn (easy criterion) required by five experimentally naïve subjects[6] was 878 as compared with 614 for the five subjects who had had previous experimental experience.[7] While the number of subjects is too small to attach any statistical significance to this difference, it is sufficiently great to require an equating of this factor when comparing subjects on other differences, age, sex, etc.

The data of the three infants are interesting. As described already, Dick satisfied only the easier learning criterion, refusing to continue work in the experiment after 240 trials. Tom was also worked at 2 years of age for 288 trials, but had to be dis-

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[5] Only one error is counted on any one trial.

[6] Mona, Pati, Josie, Nira, and Cuba.

[7] Wendy, Mimi, Lia, May, and Bokar.

continued as he worked very unwillingly. At the cessation of training he was responding no better than chance. More than a year later, when he was almost $3\frac{1}{2}$ years of age, Tom was returned to the problem. While he still worked somewhat reluctantly at times, requiring 48 days to run 33 series, he succeeded in solving the problem in 396 trials. The third infant, Bob, was just under $3\frac{1}{2}$ years of age when he solved the problem in 828 trials.

These somewhat fragmentary results suggest that there is probably little difference in the ability of the mature adult and the young 3-year-old chimpanzee to solve this type of multiple choice problem. The adaptation of the 2-year-old subjects was marked by considerably more affective behavior than the older animals. It was much more difficult to get them to work consistently, even when they were responding with considerable success. In the case of Dick, at least, this affectivity did not seem to interfere with the learning of the problem.

With a view to studying the effect of specific experience in this type of multiple choice experiment, three of the subjects, Mimi, May, and Lia, were not given the middle-box problem first as were the rest of the subjects, but only after they had solved problems 2, 3, and 4. That is, immediately following the learning of problem 4—the left-end box of seven boxes—these three subjects were presented with the middle-box problem. So far as speed of adaptation is concerned, it will be seen that there is little evidence for any difference one way or the other between these three subjects and the remainder of the group, as their scores fall at about the median of the adult subjects. A similar lack of difference is shown in the comparison in table 7 of the scores of problem 2—the second box from the left end of six boxes—in which the status of the subject's experience is reversed. In this latter problem, subjects Mimi, May, and Lia had not learned any previous problem, whereas the remainder of the group had just completed problem 1.

The most probable explanation of this failure to benefit from the experience of having just previously solved one or more multiple choice problems is that the subject must first unlearn

the previous solution before learning the new. Support for this interpretation is to be found in the distribution of errors for the different boxes in each setting. Thus, the three subjects that learned the middle-box problem last instead of first, made a disproportionate number of errors on the second box from the left end of each setting—a response which was correct in the first problem they learned. Likewise in learning problem 2 after problem 1 a very large number of the errors were responses to the center box of each setting.

C. Systematizations or generalized response tendencies during pre-solution period. During the learning of this problem there were very few instances of systematic, or as they might appropriately be termed in the present type of problem, generalized response tendencies. The three subjects that were presented with this problem after having learned three prior problems, showed a tendency to choose in accord with their last learned response—the left-end box of each setting—for the first few series, and two of the three responded systematically to the second box of each setting, which was the solution to the first problem they had learned.

Purely on the basis of the statistical criterion[8] of a systematic reaction tendency, several of the remainder of the group showed evidence, at first, of apparently responding systematically to one of the end boxes. A more critical analysis of their records, however, indicated that, in reality, their behavior consisted in responding to the box nearest to them, a response which was almost universal in the initial stages of learning. Thus, if the animal customarily sat to the right of the apparatus, the right-end box would be nearest to it on most of the settings and hence would be chosen most frequently. In this connection it is interesting to note that nearly all of the subjects exhibited a striking consistency in their manner of approaching the apparatus. Some invariably clung to the wire wall of the cage to one side of the

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[8] Seven responses out of 12 is just beyond the limit of chance expectancy in this problem. Seven or more responses to same box would be evidence of a systematic response tendency.

apparatus, while others regularly sat on the floor directly in the middle and front of the apparatus. The latter tended to choose the right-end box of the extreme left-end setting, the left-end box of the extreme right-end setting, and one of the inside boxes of the two center settings, usually box 5, 6, or 7, as they were directly in front and nearest to them.

There were, however, one or two instances of systematic response in addition to those of the three subjects already mentioned. Tom, in particular, showed a highly consistent choice of the left-end box for 11 successive series. He then shifted to the second box from the left end, and finally, after a number of periods of random response, learned always to choose the middle box. The interpretation that his learning consisted of a sequence of "relational" systematizations or "hypotheses" receives little support, however, from the control test results, which will be discussed in the next section.

Soda, similarly, showed a systematic choice of the first or left-end box of each setting, followed by a tendency to choose the second box, and finally the third or middle box. Between the latter two, however, there were a great many series of random choice of the five possible responses. Moreover, there were 24 series of training between the first systematic choice of the middle box and the attainment of the learning criterion. This latter phenomenon, the failure of the subject to maintain and bring to more or less immediate perfection this correct systematic response, is characteristic of practically every subject.

D. *Results of control series and their relation to learning.* As stated previously in the historical section, one of the evidences suggesting that successful response to this multiple choice type of problem involves the perception of, or response to, some characteristic common to the different settings (usually assumed to be the spatial relationship of the correct box to the others), is the capacity of the subject to respond accurately to a new group of settings. Successful response to such a control series not only reveals the equivalence of the new settings with the old, but also rules out the possibility that the subject has learned to

react specifically to some particular stimulus cue on the boxes themselves, or in some manner has learned the individual settings more or less independently of one another.

An examination of the control test data of table 3, which gives the percentage of correct responses made to the three new 5-box settings, reveals the fact that only one subject, Bentia, responded with 100 per cent accuracy (10/10 times) to the new settings in both control series. Four other subjects (Mamo, Soda, Wendy, and Nira) averaged 80 per cent or more correct responses on these tests, while the remainder of the scores ranged from 0 to 60 per cent.

How are we to interpret these results? Must we conclude that only one subject responded as though the new settings were equivalent to the old ones, or can we accept a score somewhat lower than 100 per cent as significant of equivalence of stimulation? Theoretically, or by chance, a score of 20 per cent would be expected on the control test, and any score to be beyond the limits of chance expectancy ($20\% \pm 3$ sigma), and hence indicative of the operation of some systematic factor, must be 50 per cent or more in the combined tests (20 trials).

Unfortunately, a test score of over 50 per cent cannot be taken as definite evidence that the solution was on the basis of the response to some common factor perceived in the different settings, for the subject might have learned some other response which would permit it to score more than 50 per cent to new settings merely by chance. For example, if the subject in the learning series should acquire the habit of avoiding the outside or end boxes of each setting, the chance of hitting the middle box of the new control series would be 33.3 per cent and the limits of chance expectancy would be up to 65 per cent. That some such tendency might have been present is shown by the fact that only 6 per cent of the group's errors during the last two-fifths of the learning period were on the end boxes, and, moreover, that not a single subject ever responded to an end box in the control series.

The possibility of responding as high as 80 per cent or more to the control settings on any other basis than one involving the perception of some generalized or common feature of the various

settings, is, of course, impossible to determine. The writer is inclined to regard it as fairly remote, and to interpret the learning of the five subjects who scored this high in the control test as being based on some type of equivalence. Support for this conclusion is to be found in the following analysis of the relation of the learning of the individual settings to the control test performance.

It occurred to the investigator that if those subjects that scored high on the control series (80% and up) really solved the problem on a different basis from those that scored low, an analytical comparison of their learning data might reveal certain differences. More specifically, it was argued that the error curves of the individual settings for those subjects that were successful in the control tests should all drop to zero at about the same point, as they were not learning specific settings, but responding to some characteristic common to each setting. On the other hand, the error curves of the individual settings for the subjects that scored low in the control tests might be expected to show a contrasting picture, there being little likelihood of the separate settings being learned simultaneously as the solution presumably did not involve generalization.

The graphs in figure 2 present characteristic curves of the two groups. It will be observed that the difference suggested in the above paragraph between their learning data is strikingly revealed. These graphs show the errors made in 5 successive learning periods on each of the 4 different settings. As each setting was presented 3 times each period, a chance error score is 12, or four-fifths of the 15 trials, and the limit of chance expectancy is 5. The point to be particularly noted is that the four curves in the upper graph all drop below the chance limit line at about the same time and are in marked contrast to the curves in the lower graph. In the latter, first one curve drops down, then a second, a third, and finally the fourth. There seems little question but that this latter subject in some manner learned each setting individually and consequently was unable to respond successfully to the new settings of the control series. It should be noted that this mode of solution had probably been rendered relatively easy

in the present problem because of the small number (4) of set-
tings employed.
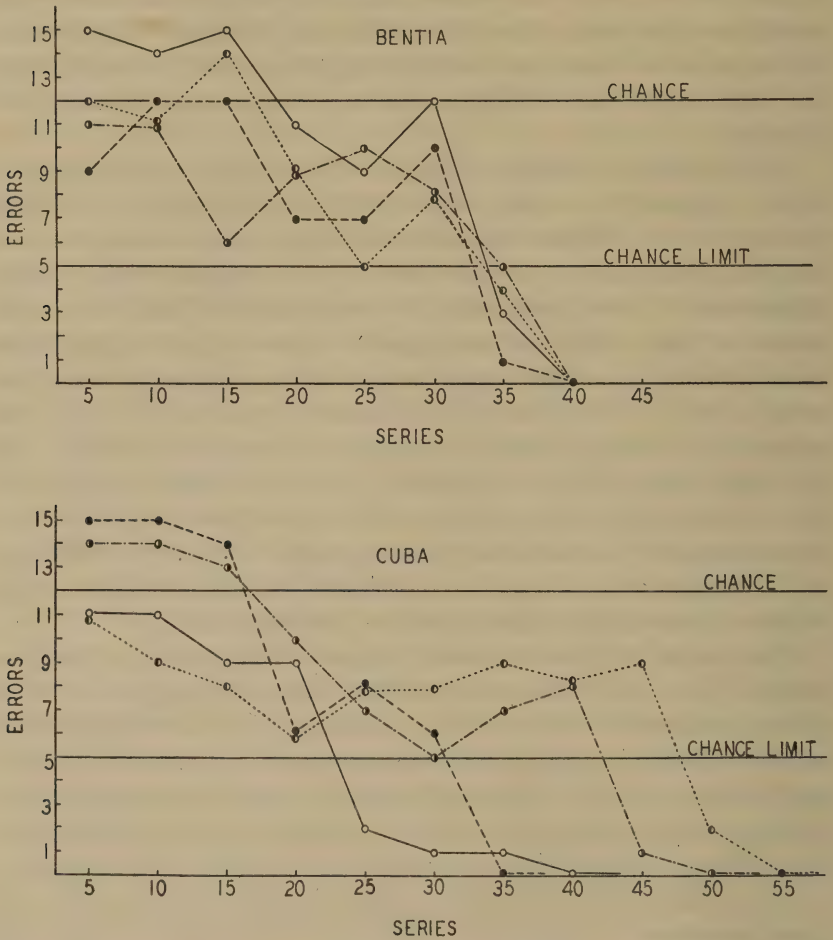
FIG. 2. SHOWING THE LEARNING CURVES OF THE FOUR DIFFERENT SETTINGS
IN PROBLEM 1

The upper graph is representative of subjects which learned all settings simul-
taneously, the lower of subjects which learned individual settings.

As a means of showing the relation between the control test
results and the learning data of all the subjects, quantitative
measures of the degree to which the individual setting curves

fall to zero at the same point or tend to fall at widely disparate points were devised; one by computing the average deviation of the trials at which the four error curves fell below 2 errors, and a second by measuring the distance (range) between the points at which the first and last error curve fell below 2 errors. These data are given in table 4, small values indicating more or less simultaneous learning of the settings while large values are indicative of specific learning. It will be seen that there is a

TABLE 4

Showing the relation between the tendency to learn all four settings simultaneously in problem 1 and the results on control tests with novel settings

SUBJECTS	CONTROL TESTS RESULTS	DEGREE OF SIMULTANEITY IN LEARNING SETTINGS	
		Average deviation	Range
Bentia....................................	100	1.5	5
Soda......................................	85	.8	2
Mamo.....................................	85	2.3	5
Wendy....................................	80	1.3	3
Nira......................................	80	1.0	3
Bokar.....................................	55	2.8	9
Tom......................................	50	2.8	7
Bob.......................................	50	9.5	29
Josie......................................	50	11.0	34
Cuba......................................	45	9.0	25
Lia..	40	13.5	36
Mimi......................................	35	12.3	40
May.......................................	35	11.8	38
Mona.....................................	30	20.0	53
Pati.......................................	0	22.3	71

remarkably close relationship between the two sets of data. Indeed, rank order coefficients of correlation (rho) between the control test results and the two measures of the degree of simultaneity of learning of the settings were $.92 \pm .03$ and $.93 \pm .03$.

Within the group of five subjects which were more or less successful in the control series, however, there is little or no correlation between the test scores and the degree of simultaneity in learning of the settings. In fact, the correlation is slightly, but not significantly, negative. On the assumption that these sub-

jects had learned the problem in terms of some generalized feature of the individual stimulus settings, one would not expect any correlation to exist, as the differences in both the control test and learning data would be merely the result of chance and thus uncorrelated factors. Within the group which scored low in the control tests, on the other hand, the correlation is very high, the two values being .89 ± .05 and .92 ± .04. This means, in general, that the more separated was the learning of the individual settings, the poorer tended to be the response of the subject in the control tests. Why differences in the degree to which the learning of the individual settings is separated should be correlated with differences in the control tests is not easy to understand. One possible explanation that suggests itself is in terms of overlearning of the response to the settings which are learned first. Thus a subject such as Cuba (lower graph in fig. 2), who had greatly overlearned settings 3 and 9, might be expected to respond in a manner appropriate to these settings, i.e., by always choosing boxes 3 and 9 when given control settings 4 and 8, and thus do poorly in the control series. Presumably the greater the amount of overlearning of any setting, the greater would be the tendency to respond in this manner.

The results of the control tests with settings of seven boxes are presented in table 5, which shows the number of responses made to each box in the settings. The subjects have been arranged in order of their success in the regular control series with 5-box settings. While there is a tendency for the middle (fourth) box to be chosen most often by the subjects that scored high in the regular control tests, it will be seen that the correlation is by no means perfect. The difference in the scores of the two groups is much less in the 7-box tests than in the previous 5-box test, for the poorer group of subjects did about as well on both tests, whereas the subjects that scored high in the 5-box tests fell down somewhat in the 7-box test. One very striking fact revealed in this table is the extent to which all of the subjects tended to respond to one of the three middle boxes of the settings, as though they had "aimed" their response at the middle or center box but lacked precision in execution. In the case of the

one test with settings of 9 boxes, Bentia chose the middle (fifth box) 60 per cent of the trials, as compared with her choice of the middle box in the 7-box settings 70 per cent of the trials and a score in the control series with the new 5-box settings of 100 per cent.

In summarizing this section, our analysis of the control test and learning data has revealed two apparently distinct types of solution. The majority of the subjects showed evidence of learning one setting at a time until all were learned, while in the case of at least five subjects, the error curves of the different settings

TABLE 5

Showing number of responses to each box in 7-box control test (problem 1)

SUBJECTS	PER CENT CORRECT 5-BOX CONTROL TEST	NUMBER OF RESPONSES						
		Boxes						
		1	2	3	4	5	6	7
Bentia.................	100	0	0	1	14	5	0	0
Soda..................	85	0	0	5	13	2	0	0
Mamo.................	85	0	0	4	12	4	0	0
Wendy................	80	0	0	11	7	2	0	0
Nira..................	80	0	0	5	9	6	0	0
Al....................	60	0	0	5	6	8	1	0
Josie.................	40	0	2	7	8	3	0	0
Cuba.................	50	0	0	9	10	1	0	0
Mona.................	40	0	2	7	8	3	0	0
Pati..................	30	0	4	6	6	3	1	0
Total..................		0	8	60	93	37	2	0

dropped to zero more or less simultaneously. The interpretation that the latter group solved the problem on the basis of generalization, the perception of some equivalence of the different settings, is supported by the fact that these subjects responded with high accuracy to a control series of new, but similar, settings, whereas the subjects who learned the individual settings responded poorly to the new control settings. This result thus corroborates and extends the findings of Yerkes' experiment (24), in which he showed by means of control tests that the solution of such problems by chimpanzees may sometimes be

independent of such cues as the order of presentation of the correct boxes or specificity of the settings. Yerkes gave the term "discovery" to this type of solution and interpreted it as radically different from blind trial-and-error-learning.

IV. PROBLEM 2. SECOND BOX FROM LEFT END OF SIX BOXES

Conditions during preliminary insoluble series

Within one or two days following the completion of the control tests of problem 1, eight subjects were given, as a preliminary to problem 2, 10 daily series of 12 trials, in which the settings consisted of 6 boxes each, no particular box of which was consistently correct. The settings used, their order of presentation in the series, and the particular box reinforced (shown in italics) were as follows:

Trial	Setting						Trial	Setting					
1	3	*4*	5	6	7	8	7	1	2	3	4	5	*6*
2	5	6	7	8	*9*	10	8	*3*	4	5	6	7	8
3	1	2	3	4	*5*	6	9	5	*6*	7	8	9	10
4	*2*	3	4	5	6	7	10	2	3	4	*5*	6	7
5	6	7	8	*9*	10	11	11	4	5	6	7	8	*9*
6	4	5	6	7	*8*	9	12	6	7	*8*	9	10	11

During this insoluble series the subjects were allowed to continue opening the boxes until the correct one was selected. Because of various unavoidable circumstances (extremely cold weather, sickness of animal or experimenter, etc.), there were several interruptions in the work of some of the subjects. With one exception, however, the 10 series were completed within 16 days. In addition to these eight subjects, three others who had not had any previous experience in multiple choice work were used. They were the same three subjects (Mimi, May, and Lia) that were used later in the middle-box problem and whose data were included in the discussion of that problem.

Conditions during regular and control series

Training on the regular problem was instituted on the day following the completion of the insoluble series. The same 6 settings were used. Two series of 12 trials were given each day,

a rest period of 5 or 10 minutes being inserted between them. As in the preliminary series there were occasional brief interruptions in the training. The orders of presentation of the settings, designated by the correct box (2d from left), were as follows:

> Learning Series A: 7 5 3 6 4 2 5 7 3 2 6 4
> Learning Series B: 2 4 6 3 7 5 2 4 6 3 5 7

The procedure of permitting response until successful was employed throughout this problem. Learning was considered complete when all 12 trials of a single series were correct. No systematic control series were given all of the subjects following learning, as there were no new settings of six adjoining boxes available, all the possible ones having been used in the training. However, four of the subjects were given a control series with the settings of problem 1, and two others were presented with 4-box settings.

Results of preliminary insoluble series

The data of this series are of interest and value from several points of view. First, they incidentally show that successful response by the subjects was not mediated by a secondary visual or odor cue provided by the presence of the lure under the correct box. The average number of correct responses per series of 12 trials for the eleven subjects was 2.03, which is negligibly different from the theoretical chance score of 2.0. The individual scores ranged from 1.8 to 2.4.

A second feature of these data is that the trials on the first day provide still another control test for the eight subjects that had just completed problem 1. Dividing these subjects into two groups on the basis of their results in the original control test with the novel 5-box settings, it was found that those who had scored high, again responded a large percentage of trials to either of the two middle boxes. The four subjects in this group averaged 83 per cent (range 75–92%) of their responses to the two middle boxes. Of the four remaining subjects, three had done poorly in the original control test and had shown definite evidence of learning individual settings; the fourth, Al, had failed to com-

plete the learning and had responded somewhat ambiguously (60%) in the control test. While these latter subjects responded on the average a somewhat fewer number of times to the two middle boxes of the 6-box settings than the former group, their scores, with one exception, were surprisingly high (42%, 67%, 75%, 100%). Whatever the nature of the perceptual processes, there was certainly at this time a significant general tendency for the response to be directed to the middle of each setting.

The most important phenomenon revealed during this insoluble series, however, was the extent to which systematic response

TABLE 6

Showing the systematic reaction tendencies exhibited by the various subjects in the preliminary insoluble series of problem 2

SERIES	GROUP A				GROUP B				GROUP C		
	Wendy	Bentia	Soda	Mamo	Mona	Josie	Pati	Al	May	Lia	Mimi
1	(4)	3	3	*4*	2	*3*	(3)	3	(1)	(1)	(6)
2	5	*3*	4	*4*	2	*4*	4	3	(1)	*1*	(6)
3	4	*3*	3–4	*5*	*2*	*4*	(4)	2	1	1	6
4	*5*	*3*	*4*	*5*	2.3	(4–5)	(3–4)	2	1	(1)	(6)
5	*5*	4	3–4	*4*	2	5	(2–4)	*2*	1	1	6
6	*5*	4	3	*4*	2	4	(3)	*2*	*1*	(1)	(1–3)
7	4–5	*3*	3	*4*	(2)	5	(5)	3	*1*	*1*	(6)
8	(5)	(3)	*3*	*4*	2	(5)	(4)	2	1	(1–4)	*6*
9	*5*	*3*	3	*4*	(2–3)	(5–6)	(4)	2	*1*	(1)	*6*
10	*5*	3–4	3	4	2	*6*	(5)	2	*1*	1	(6)

tendencies continued to be exhibited by the various subjects, and the changes they underwent during the series in spite of the fact that no one response was systematically rewarded. Table 6 shows the particular reaction tendencies exhibited by each of the subjects throughout the 10 daily series of trials. The limit of chance expectation of responding to the same relative box in the different settings is 5.84, so a response of 6 out of 12 trials was adopted as the criterion of a systematic response. Whenever the same box in the different settings, the second, third, etc., was responded to first 6 or more times in a series, that box is listed in table 6. When 8 or more similar responses were made, italicizing is used to indicate the greater statistical significance; the

series in which there was no systematic response, the box or boxes responded to most often are shown in parentheses. The subjects have been divided into three groups: those which had just completed problem 1 were grouped together according to the extent to which their response in the original control tests of that problem exhibited generalization (Group A) or specificity (Group B); the third group (C) consists of the three subjects that had not learned any previous multiple choice problems.

An inspection of this table shows that all subjects exhibited one or more systematic response tendencies during this period, and that, as one might expect, the Group A subjects' responses were almost invariably of this type. It will also be observed that, with the exception of Wendy, the subjects of this group tended to retain their response to one or other of the middle boxes throughout the period. Wendy soon shifted to the fifth box (numbering from left end) and continued to respond to it with high consistency. The subjects of Group B showed a more ready shift to a different response, which would seem to be in agreement with the interpretation of the previous section that their response to the center box of the setting had not involved such a strong degree of generalization. Mona and Al responded most often to the second box of each setting, while Josie shifted first to the fourth, then to the fifth, and finally, in the last experimental session, to the sixth or extreme right-end box. The fourth animal, Pati, did not respond systematically to any one box except for a single session.

Just why these latter four subjects should have exhibited such systematic response tendencies is not altogether clear. This evidence suggests either that their responses were not altogether specific in problem 1, or that with the appearance of new, unfamiliar settings in the various control series, their specific responses were broken down and they tended to adopt a more generalized mode of response. That the systematic responses were not produced by learning certain of the individual settings is ruled out by the fact that the choices were distributed evenly over the six different settings. It is fortunate that one has this check on the nature of the systematic response in this type of

situation, for obviously the method of learning the specific settings can also result in the attainment of the statistical criterion for a systematic reaction tendency. That is, the latter criterion alone does not necessarily mean that the response is what we would term a generalized reaction tendency.

The further criterion of equally consistent response to all settings must also be met. It is only when this latter criterion is satisfied that the subjects respond successfully to the control series, and it is only in such instances that we would regard the response as a generalized response tendency.

The data of the three chimpanzees of Group C is in sharp contrast to that of the other two groups, with the end boxes being responded to most often. As in the case of the initial adaptation of those subjects who learned problem 1 first, these three subjects tended at first to respond directly to the box nearest to them. Hence, their consistent choice of either the left or right-end box was at first largely due to the fact that a more or less constant position either to the right or left of the apparatus was maintained. Thus, Mimi usually climbed up the wire cage-wall slightly to the right of the center of the apparatus so that the nearest box in most settings was the sixth. Lia, on the other hand, usually sat to the left of the middle of the apparatus and hence the first box of each setting was most often the nearest to her. May's response was similar to Lia's in the first few periods, but during the last two she responded to the extreme left-end box on every trial quite independently of whether or not it was the nearest to her. During these two periods she was definitely responding with a generalized tendency[9] to take the left-end box.

Results of regular learning series

A. *Learning data.* The solution of this second problem proved to be much easier for the chimpanzees than the middle-box problem. Table 7 shows that the eleven subjects required an average of only 281.5 trials to learn it, as compared with an approximate average of 777.8 trials for them to learn the middle-

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[9] Both the ordinary statistical criterion of a systematic reaction and the criterion of equally consistent response to all settings were met.

box problem.   That this greater simplicity of the second-box
problem was not due to the experience gained from having solved
a previous problem is shown by the data of the three animals
at the bottom of the table.   These three subjects, it will be re-
called, learned the second-box problem first.   Their average of
344 trials is not only much smaller than the average number of
trials subsequently required for the middle-box situation (900
trials), but it is also much less than the number of trials needed

TABLE 7

*Showing the learning data of problem 2 and the relation between speed of learning
and distance of initial response tendency from the correct response*

SUBJECTS	LEARNING DATA		INITIAL RESPONSE TENDENCY
	Number of trials	Number of errors	
Bentia.........................	156	88	3
Mona...........................	168	64	2
Soda...........................	180	96	3
Al.............................	204	94	2
Mamo..........................	264	188	4
Pati...........................	312	145	(4) preference
Wendy..........................	348	222	5
Josie..........................	432	319	6
May............................	276	192	1
Mimi...........................	336	234	6 nearest box
Lia............................	420	281	1 nearest box
Mean..........................	281.5	174.8	—

for solving the middle-box problem by those subjects that learned
it first.
A factor which appears to be of no little importance in deter-
mining the speed with which solution was attained in this problem
is the particular response tendency that the subject brings to the
problem.   The original purpose in giving the preliminary insoluble
series before the second problem was to break up any reaction
tendencies which the subjects had acquired from the previous
problem.   As we have seen, however, the reaction tendencies
did not disappear; some subjects continued to maintain the

same response and some shifted to a different one. The final column of table 7 shows the particular response tendency that each subject brought to the second-box problem. Confining our attention for the moment to the eight subjects that had previously learned the middle-box situation, it will be observed that there is a very close relationship between the nearness of the initial reaction tendency to the correct response and the speed of solution. The reason for this, as we shall see, is that the chimpanzees were apparently unable to shift directly from the fourth or fifth box to the second. If a subject was responding to the fifth box, he shifted first to the fourth, then to the third, and finally to the second box.

In the case of the three subjects in the lower part of the table, one of them, May, was responding systematically to the first box at the beginning of the problem while the other two were merely responding to the box nearest to them. As it was their first problem their records are not comparable with those of the other subjects. It is interesting to note that May, who had acquired a systematic left-box response in the preliminary series, solved the problem before the other two subjects. The latter, as we shall see below, first acquired the response of opening the left-end box and only then learned the correct one.

B. Systematic response tendencies. The pre-solution period of this second-box problem differed markedly from that of problem 1. In the latter, it will be recalled, there were only a few isolated instances of systematic response tendencies, while in the present problem quite the reverse was the rule. Table 8, which gives the same type of data as table 6 did for the preliminary series, shows the extent to which such systematizations prevailed. Particularly interesting is the manner in which the subjects shifted gradually from a distant box to the correct one, responding systematically in turn to each of the intervening boxes. For example, Josie began with a systematic choice of the sixth box of each setting, shifted to the fifth, vacillated between the fifth and fourth for several periods, then went to the third, and finally after 264 trials began to respond systematically to the correct box. Wendy's data shows a similar sequence of shifts

TABLE 8

Showing the systematic reaction tendencies exhibited by various subjects in learning problem 2

SERIES	GROUP A				GROUP B				GROUP C		
	Wendy	Bentia	Soda	Mamo	Mona	Josie	Pati	Al	May	Lia	Mimi
1	*5*	3	*3*	4	(1–2)	6	(1–5)	*2*	*1*	(1)	(3–6)
2	*5*	3	*3*	3	*2*	5	5	*3*	*1*	*1*	1
3	5	3	(3)	3	2	5	4	*3*	*1*	1	(1–6)
4	4	3	3	4	3	4	4	*3*	*1*	*1*	(1)
5	*4*	3	2	3	(2)	5	(4)	2	*1*	*1*	(1)
6	4	*3*	3	4	2–3	*5*	(2)	2	(1)	*1*	*1*
7	*3*	*3*	*3*	3	*2*	(4)	(3)	3	*1*	*1*	*1*
8	*3*	*2*	*3*	4	2	4	2	*2*	2	*1*	1
9	*4*	2	3	*3*	2	(4)	(2)	2	1	*1*	*1*
10	3	*2*	2	*3*	2	(4–5)	2	*2*	(1)	*1*	*1*
11	*5*	*2*	(2)	3	*2*	*5*	(2–3)	2–3	(1)	*1*	*1*
12	3	*2*	*2*	(1)	*2*	5	*2*	(2–3)	(2–3)	*1*	*1*
13	2	*2*	*2*	*1*	*2*	5	2	2	*1*	*1*	1–2
14	2		*2*	*1*	*2*	*4*	*2*	*2*	(2)	*1*	1
15	3		*2*	1		4	(2)	*2*	(5)	*1*	1
16	2–3			*2*		*3*	2	*2*	(2)	*1*	1
17	*3*			*2*		(3–4)	*2*	*2*	2	*1*	*1*
18	*2*			*2*		3	*2*		(2)	*1*	1
19	(2–3)			*2*		3	*2*		2	*1*	1
20	*2*			*2*		3	*2*		(2)	1	2
21	*2*			*2*		3	*2*		*2*	1	3
22	*2*			*2*		3	*2*		(2)	1	(2)
23	*2*					*2*	*2*		*2*	1	(2)
24	*2*					*2*	*2*			1	*2*
25	*2*					*2*	*2*			*2*	*2*
26	*2*					*2*	*2*			*2*	(2–4)
27	*2*					3				2	*2*
28	*2*					2				*2*	*2*
29	*2*					*2*				*2*	
30						3				*2*	
31						*2*				2	
32						2				2	
33						*2*				1–2	
34						2				1	
35						2				*2*	
36						*2*					

from the fifth box to the second. An interesting observation in connection with this subject's record was the regression to the

fifth box in the 11th period after having shifted as far as the third box in the previous experimental period. The explanation is not unlikely related to the fact that there was an interval of 5 days between the 10th and 11th learning periods. Such behavior is suggestive of the phenomenon of spontaneous recovery from experimental extinction in conditioned response experiments. Figure 3 presents a graphic picture of the learning data of Wendy (upper) and Mimi (lower), which shows in more detail the shifting distribution of responses. These curves give the number of times each of the boxes was chosen in a series. The curve for the correct second box is, in effect, a curve of learning.

The performance of Al and Mona in this problem is of considerable interest because each of them had, in the preliminary insoluble series, settled upon what was to be the correct response. With this initial advantage, both naturally showed comparatively quick learning. Surprising, however, was the shift back to the third box, particularly marked in the case of Al, when systematic reinforcement was given to the second box. In the first series with systematic reinforcement of the second box, it appeared as though Al was going to attain solution almost immediately, for he chose the second box 10 of the 12 trials. In the next period, however, he reverted almost completely to the third box, taking it 10 times and the second box only twice. He persisted in this preference for the third box for two further sessions and then went back to box two. Such a rapid and complete shift from a systematic response, which is correct and being reinforced, to an older, and now inappropriate, response is more suggestive of what has been termed trial and error variation in learning behavior than insightful selection and adoption of a response.

Another point of interest in connection with this problem is the over-shooting of the mark by the animals. That is, as the subjects shifted their response towards the correct second box, they tended to go beyond it. This tendency was most marked in the case of Mamo, who shifted from the third to the first box and then back to the second. All of the subjects exhibited this over-shooting of the mark, although not always to such a degree as to show a systematic response.
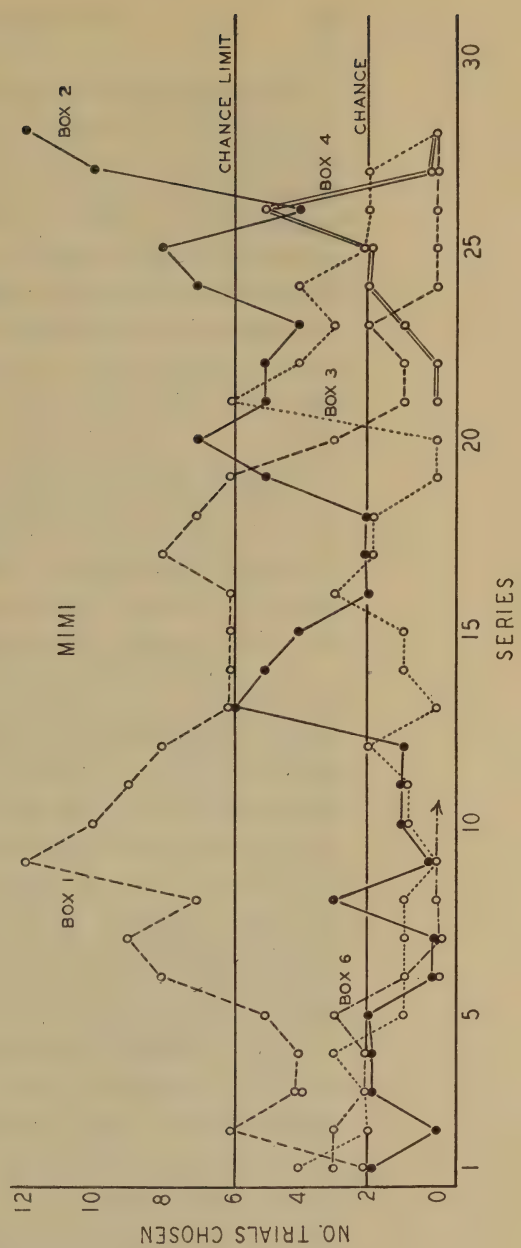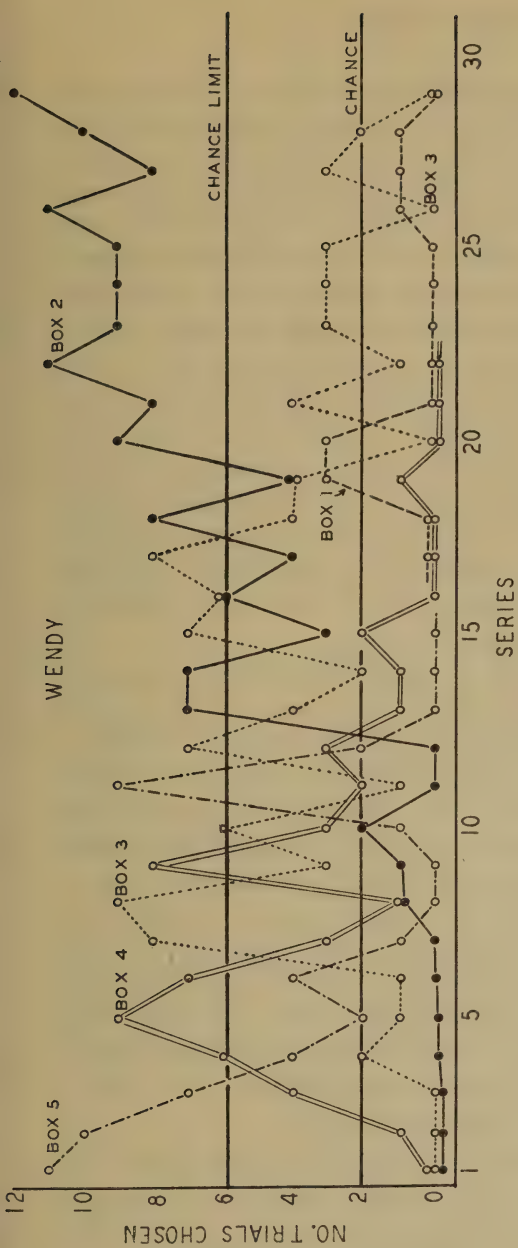
FIG. 3. SHOWING THE SEQUENCE OF REACTION TENDENCIES EXHIBITED BY WENDY
AND MIMI IN LEARNING PROBLEM 2, THE SECOND BOX FROM LEFT END OF
SIX BOXES

35

The sequence of systematic reaction tendencies exhibited by May, Lia, and Mimi, it will be seen, presents a quite different picture. Reference has been made to the fact that at the end of the preliminary series May had definitely adopted the response of opening the left-end box, while Mimi and Lia were still responding to the box nearest to them. Before solving the problem the latter two adopted the response to the first box. With the beginning of training on the regular learning problem, Mimi abandoned the habit of climbing on the wire to the left of the apparatus and instead sat on the floor directly in front of the center of it. Consequently, her response record at the beginning of learning does not show a systematic choice of the sixth box as was the case in the preliminary series. Beginning with a random response, Mimi shifted to, and brought to perfection, the response of opening the first box of each setting. In abandoning this she showed a marked tendency to shift too far and take the third box and sometimes even the fourth box.

C. Control series. In a series of trials with 4-box settings, 2 boxes having been eliminated from the right end of each regular setting, Al and Bentia each responded correctly 11 out of 12 trials. When presented with the 5-box settings of problem 1, Josie responded every trial but one, and Wendy, Pati, and Mona 10 out of 12 trials to the second box. In the first problem Wendy was the only one of these four subjects to respond correctly a significant number of times in the control tests. Analysis of the learning data tends to be in agreement with these high control test scores, for all subjects, with the exception of Mona and Pati, showed more or less simultaneous learning of the 6 individual settings. Mona learned the 2 outside settings and Pati the 2 left-most settings somewhat ahead of the remaining four, which seemed to have been learned at the same time.

A conclusion that would seem to be warranted from these data is that the learning of this second-box problem involved many more systematic or generalized reaction tendencies than in the case of the middle-box problem. Whether this difference was due to the particular characteristics of the problem, e.g., its greater simplicity, or due to the fact that the subjects were more

experienced, is not altogether clear. Arguing against the latter are the performances of the three subjects that learned the present problem first. All showed systematic reaction tendencies in the pre-solution period and in no instance was there any evidence of learning the settings individually. On the other hand, when they subsequently learned the middle-box problem they learned the individual settings separately and did not exhibit systematic response tendencies except at the very beginning of learning.

V. PROBLEM 3. RIGHT-END BOX OF SEVEN BOXES

Conditions during learning series

Two series of 10 trials with a 10-minute rest interval between them were given daily. In each series 5 different settings of 7 boxes were each used twice. The orders of presentation of the settings, designated by the correct 7th, or right-end box, were as follows:

Learning Series A: 8 10 7 9 11 9 8 11 7 10
Learning Series B: 11 9 7 10 8 11 7 9 8 10

The criterion of learning was a perfect series of 10 trials. Throughout the learning period the correction procedure was followed, all of the boxes being unlocked and the subject being permitted to continue responding until successful.

Conditions during control series

A single control series was given each of the eleven subjects. It consisted of 10 different settings made up of varying numbers of boxes. The settings, designated by the two extreme boxes, were presented according to the following arrangement:

1.	1–5	6.	1–3
2.	3–6	7.	3–7
3.	6–8	8.	3–8
4.	2–9	9.	9–10
5.	3–4	10.	1–4

Experimental results

A. *Learning series.* Following directly upon the completion of problem 2, all of the subjects began each trial by responding to

the second box of each setting.   With failure of reinforcement of this response, there began a shift of response to boxes nearer the right end.   Table 9 shows the sequence of first choice responses made by each of the subjects in this problem.   As in tables 6 and 8, the numbers indicate the boxes to which systematic responses, in this instance 5 or more of the 10 trials, were made.   When 7 or more responses to the same box were made in a series, the fact

TABLE 9

Showing systematic reaction tendencies exhibited by the various subjects in the learning of problem 3

SERIES	SUBJECTS										
	Wendy	Bentia	Soda	Mamo	Mona	Josie	Pati	Al	May	Lia	Mimi
1	(3)	*2*	*2*	*2*	*2*	2–3	2	3	*2*	*2*	2
2	(6)	*4*	(4)	2	2–3	(4)	(6–7)	(4)	(3)	(6)	*7*
3	(3–6)	5	(2)	*1*	(2–4)	(3)	(6)	(4)	(3)	(6–7)	*7*
4	7	6	2	*1*	3	*7*	6–7	(5)	*7*	*7*	*7*
5	7•	6	1	*1*	(5)	*7*	(7)	(5–7)			
6	*7*	*6*	(1–3)	*1*	5	*7*	7	*7*			
7		5	(2–3)	*1*	(5)		7	*7*			
8		(6)	(2)	*7*	(5–6)		*7*	*7*			
9		6	*2*		*7*		7				
10		(6)	(3)		(5–6)		*7*				
11		6	7		*7*		*7*				
12		7	*7*		*7*		*7*				
13		*7*			*7*						
14		*7*			*7*						
15		*7*			*7*						
16					6						
17					*7*						

has been indicated by italicizing.   A number in parentheses represents the modal response, or the box which was chosen most often in a series in which there was no systematic response.   Inspection of the table reveals several different ways in which learning proceeded.   Bentia and Mona, and to a lesser extent Wendy and Al, showed a shifting from one box to the next similar to that in the previous problem.   In contrast, subjects such as Mimi, Lia, May, and Pati skipped most or all of the boxes between

the second and the seventh, responding on only a few occasions to them.[10]

Soda and Mamo present a still different picture. The latter's performance, visualized in figure 4, is particularly interesting,
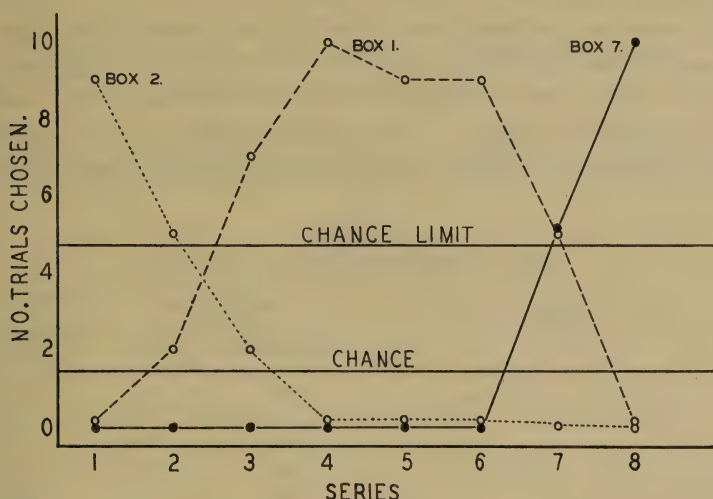

FIG. 4. SHOWING THE SEQUENCE OF REACTION TENDENCIES EXHIBITED BY MAMO
IN LEARNING PROBLEM 3, THE RIGHT END OF SEVEN BOXES

for instead of skipping in the direction of the right end of the settings, she chose the first or left-end box after abandoning the second. She persisted in this response for 4 series. In the follow-

[10] Attention should be called to the fact that in shifting from the 2nd to the 7th box all of the subjects made some responses to the intervening boxes, which were quickly abandoned for boxes nearer to the correct one. Such relatively speedy adaptation does not permit a sufficient number of responses to be made to each of these boxes for them to become classified as "systematic response tendencies" or as Krechevsky terms them "hypotheses." It is only the persistent, perseverative errors that attain this distinction. It is in light of such facts that the writer is forced to disagree with Krechevsky's interpretation of these "hypotheses" as being insightful, or intelligent responses. Indeed, in a sense, the opposite would seem to be the case, for in order to classify as a "hypothesis," a response, although non-adaptive, must continue to be made a certain minimum number of times in blind fashion. A maladaptive response which is quickly and intelligently abandoned cannot become a "hypothesis."

ing series she chose the left-end box in the first 5 trials and the right-end box in the last 5 trials. All responses in the next series were to the correct right-end box. Soda also shifted to the left-end box, but subsequently went back to the second and then jumped from there to the seventh.

This end-box problem proved to be much easier than either of the two previous problems, as may be seen by comparing the data of the first two columns of table 10 with the corresponding data in tables 3 and 7. The mean number of trials for this group of eleven subjects in the present problem was only 88.2

TABLE 10

Learning and control data of problem 3

| SUBJECTS | LEARNING DATA | | CONTROL DATA |
	Trials	Errors	PER CENT CORRECT
Mimi	40	11	90
Lia	40	25	90
May	40	27	50
Wendy	60	31	90
Josie	60	32	100
Al	90	48	100
Mamo	90	65	100
Pati	120	57	80
Soda	120	103	90
Bentia	140	104	100
Mona	170	112	100
Mean	88.2	55.9	90%

trials, compared with 777.8 trials for these subjects in problem 1 and 281.5 trials for problem 2. The error data show similar differences.

B. Control series. The results of the control test, in which settings varying in the number of their boxes were used, are shown in the final column of table 10. It will be seen that with the exception of May and Pati, no subject made more than one error in the 10 trials and five had perfect records. For some unaccountable reason May made a score of only 50 per cent correct in the control test, while Pati responded correctly 80 per cent

of the trials. None of the subjects, including May and Pati, showed any evidence of learning the settings individually. So far as this end-box response is concerned, it would appear that varying the number of boxes in the settings makes little or no difference.

VI. PROBLEM 4. LEFT-END BOX OF SEVEN BOXES

Conditions during learning series

The same settings and order of presentation employed in problem 3 were used in this new problem. However, the lure

TABLE 11

Learning data for problem 4

SUBJECTS	NUMBER OF TRIALS	NUMBER OF ERRORS	ERRORS ON INDIVIDUAL BOXES					
			2	3	4	5	6	7
Mamo	20	7	0	0	0	0	0	7
Wendy	20	8	2	1	0	0	1	4
May	40	8	5	0	1	0	0	2
Al	40	9	4	0	1	0	0	4
Mimi	40	15	6	2	1	0	0	6
Soda	40	18	2	0	0	1	0	15
Bentia	40	21	10	1	0	1	1	8
Mona	50	20	6	4	2	1	1	6
Josie	50	27	6	3	1	0	0	17
Pati	60	29	12	3	2	5	2	5
Lia	120	45	37	4	0	0	0	4
Mean	47.3	18.8	8.2	1.6	0.7	0.7	0.5	7.1

was placed in the left-end box of each setting instead of the right-end box. All other experimental procedures were identical with those in problem 3.

Experimental results of learning series

The solution of this problem was accomplished with comparative ease by most of the subjects. Table 11 presents the statistical data, the errors made on the individual boxes of the settings being included with the usual data on total number of errors and number of trials required to learn. It will be seen that there

was a marked reduction in both the number of errors and trials to learn from the previous right-end box problem. This reduction resulted to some extent from the more ready abandonment of the previously correct response, but mostly because relatively few responses were made to the intermediate boxes of the settings. Pati, Bentia, and Mona showed some tendency to shift from one box to the next, but the shift was very rapid. Mamo shifted directly from the seventh to the first box and several other subjects skipped most of the intervening boxes.

An interesting example of interference of a previous solution in the learning of a problem was provided by Lia. In the very first period Lia shifted from the seventh to the first box, responding to the latter 4 out of the last 5 trials. In the two following periods she chose the first box 7 out of 10 trials and seemed to be nearing the completion of learning. Suddenly, however, she began to respond to the second box, which it will be recalled was the correct response to the first problem she had learned, and for the next several series she responded about equally often to the first and second boxes. Finally, after 110 trials of training, Lia succeeded in responding without making an error.

VII. PROBLEM 5. RELEARNING OF MIDDLE BOX OF FIVE

In an attempt to study the effects of the experience gained in learning several different multiple choice problems, the original middle-box-of-five problem was again presented to four of the subjects, Wendy, Josie, Pati, and Mona. Training was begun 8 days following the completion of the left-end box problem. Approximately 10 weeks had elapsed since the completion of the original learning by Wendy; 6 weeks, by Josie; and 7 weeks in the case of Mona and Pati. The experimental conditions for both the learning and the control series were identical with those in the original presentation.

Experimental results

A. Learning series. The initial response of all four subjects was to open the left-end box of each setting, as this response had been learned most recently. With non-reinforcement, how-

ever, it was quickly dropped. Indeed, three of the subjects responded to it only 5 of the 12 trials in the first experimental period. Table 12 shows the systematic responses (box number) made throughout the pre-solution period. As in tables 6, 8, and 9, the numbers in parentheses indicate the preferred boxes in series in which the criterion of a systematic reaction (7 or more) was not attained. The italicized numbers indicate 9 or

TABLE 12

Showing systematic reaction tendencies exhibited by various subjects in problem 5, relearning middle box of five boxes

SERIES	SUBJECTS			
	Wendy	Pati	Josie	Mona
1	(1)	(2)	(1)	*1*
2	(2–3)	(3)	(1)	(5)
3	2	(3)	*5*	5
4	(3)	(3)	*5*	3
5	3	*3*	*5*	*3*
6	3	3	*5*	*3*
7	*3*	*3*	(1–2)	*3*
8	2	4	(1–2)	*3*
9	*3*	4	(2)	*3*
10	3	*3*	(3)	*3*
11	*3*	(3)	(2–3)	*3*
12	(2)	(3)	(3)	*3*
13	(3)	(3)	(2)	*3*
14	*3*	*3*	(3)	
15			(3)	
16			*3*	
17			*3*	
18			*3*	
19			*3*	
20			*3*	

more choices. It will be observed that two of the animals, Josie and Mona, shifted their response directly from the first to the fifth or right-end box. Josie subsequently went back to the left-end, responding to either box 1 or 2 before finally learning the correct middle-box response. Wendy and Pati, on the other hand, shifted from the first to the second box, the latter within the first experimental period. Both then shifted to the middle

(third) box, but did not immediately solve the problem. Instead, Pati shifted over to the fourth box in two experimental periods, while Wendy reverted to the second box twice before attaining the criterion of solution. These are further instances of variation in behavior away from the correct response despite the fact that it was being systematically reinforced, to which reference was made in connection with Al's behavior in problem 2.

Considerable saving was effected in the relearning of this middle-box problem over the original learning by all subjects. As may be seen from an examination of table 13, which presents comparable data on learning and control tests for the two oc-

TABLE 13

Showing the relation between learning and relearning of middle-box problem

SUBJECTS	ORIGINAL LEARNING			RELEARNING		
	Trials	Errors	Control tests	Trials	Errors	Control tests
			per cent			*per cent*
Wendy...................	588	389	80	168	71	40
Josie.....................	1068	564	50	240	154	80
Mona.....................	1080	626	40	156	60	40
Pati......................	1416	862	0	168	81	60
Mean...................	1038	610	42.5	183	91.5	55

casions, each of the four subjects showed very great reduction in both error and trial scores. In fact, fewer trials were required, on the average, to relearn this middle-box problem than were needed to learn the problem in which the second box from the left end was correct. This result is in disagreement with the evidence of Yerkes' experiment with chimpanzees (24), in which he found that a problem was not solved more readily on re-presentation than originally. The explanation of this difference is probably to be found in one of the two reasons which Yerkes gives to account for his surprising result, namely, the influence upon the affective status and attitude of his subjects of a series of problems which had proved too baffling for them. The sub-

jects of the present experiment had experienced no such series of failures.

B. Control series. With a record of having responded systematically, that is, with generalized reaction tendencies throughout the pre-solution periods of problems 2, 3, and 4; and with the appearance of these incorrect systematizations in the early periods of the present problem, it was believed that the learning of all four subjects would be of the generalized rather than specific type. Moreover, during the first three learning periods there was no evidence of differential learning of the individual settings. However, with the disappearance of the incorrect systematizations and the beginning of responses to the third or middle box, the analysis of the responses to the individual settings began to show evidence of differential learning in the case of three of the subjects. Thus, Mona learned setting 9 first, then setting 4, and finally the two middle settings 5 and 7. This was exactly the same order of learning as occurred in her original learning. Pati learned setting 9 very quickly; setting 4 was learned next, and then settings 6 and 8. Wendy, who had not learned specific settings in the original learning and had responded with 80 per cent accuracy to the control series, exhibited very irregular learning of all four settings. However, setting 3 was learned somewhat before the other three, followed quickly by settings 7 and 9. Setting 5 was learned with considerable difficulty, almost twice as many errors being made on it as on the next most difficult setting.

The fourth subject, Josie, was the only one that failed to show any evidence of learning the specific settings, the error curves of the four settings falling to zero almost simultaneously. Consistent with the findings of the original learning, Josie was also, as the last column in table 13 shows, the only one of the subjects to respond with an accuracy of 80 per cent to the control tests. The scores of the subjects that learned the specific settings ranged from 40 to 60 per cent. The results of this relearning of the middle-box problem thus corroborate the finding of the original

learning that two distinct types of response, a generalized form and a specific type, are involved in its solution.

VIII. GENERAL DISCUSSION OF RESULTS

Instead of interpreting the successful response to these multiple choice problems as being based on the perception of the relevant spatial relationship of the correct box to the others of the setting, we have chosen to describe it in more general terms as involving the perception by the subject of some equivalence, some common feature possessed by all the settings. It is difficult to be more specific than this because there is little in our statistical data or behavioral observations which will support further delimitation. Nevertheless, a brief consideration of what such equivalence might consist in will not be without value for furthering our understanding of the solution of this type of problem situation by infrahuman subjects.

In the beginning it should be made clear that in using the term perception, the writer has reference to a definite response (overt or implicit) on the part of the subject, which becomes conditioned during training to the external pattern of stimulation. Such conditioned perceptual responses to an external stimulus are, or become through their proprioceptive consequences, important contributors to the total pattern of stimulation acting at the time of the subsequent response of opening a box by the animal. In the present experimental situation any acts which the subject performs between the first sight of a setting and the response of opening a box become a part of the stimulus pattern present at the time of the latter, and hence become a conditioner of it. When the box opened is correct and followed by reward, not only is there conditioning of the response of opening a box to this particular pattern of stimulation, but there is also a strengthening of the tendency to respond to the first sight of the setting by the particular intervening act or acts that took place. Thus, if, in problem 1, the subject were to fixate successive boxes from the left or right-end, the response of opening the box following 3 fixations would be successful and this latter mode of re-

sponse, three fixations, would be adopted, with the final opening response becoming conditioned to the total stimulus pattern present at the moment of completion of the third fixation response. The stimulus pattern after the second or fourth fixations would not tend to become conditioned to the box-opening response because reinforcement does not follow them. In human subjects these perceptual responses would very likely be more or less implicit, probably involving some kind of symbolic, verbal response. The equivalence of the different settings need not, then, be an external or objective part or aspect of them, but instead may reside in the common proprioceptive cues of the total stimulating pattern (sight of setting plus proprioceptive cues from immediately preceding acts).

As was stated at the beginning of this discussion, there is no very good evidence as to what the nature of such perceptual responses might have been in the case of the chimpanzees, particularly those that showed a generalized response, as evidenced by the ability to respond with success to novel settings. One possible cue is the observation that the subjects of problem 1 that were successful in the control tests usually went to the far side of the cage between trials and thus approached the apparatus from a distance. From such a position, it will be noted, the visual appearances of the different settings are more alike than from a close position, whether immediately in front of the apparatus or to one side. Moreover, the approaching responses to the different settings from a distance are more likely to be similar than responses from a near position. Both of these factors would tend to favor the ready generalization of any response to the different settings by these subjects. From a near position, on the other hand, the different settings would not appear so similar and hence there would be less likelihood of a transfer or generalization of a response from one setting to another. The observation was also made that, as these subjects approached, they gave the appearance of attempting to place themselves equidistant from the two ends of the setting. They would glance from one of the settings to the other and adjust their position to the

right or left as the case might be. While this latter behavior was also exhibited by some of the other subjects, it appeared with much less frequency and constancy in the pattern.

That the generalized mode of solution exhibited by five of the seventeen subjects in problem 1 was not altogether a function of some special ability possessed by these subjects alone is shown by the fact that Wendy, who had exhibited this type of solution in the original learning, learned specific settings in the subsequent re-presentation of the problem. Moreover, all of the subjects showed generalized modes of response in each of the other problems, while Josie relearned the middle problem by generalization whereas she originally learned by the specific method.

The manner of shifting of the generalized reaction tendencies toward the appropriate box, particularly during the pre-solution periods of problems 2 and 3, is extremely interesting for the light it throws upon the nature of the response. The behavior record of the chimpanzees is here strikingly similar to that of the marksman aiming at a target. For example, at first most of the responses of a subject may be made to the fourth box of each setting, with a few responses to the third and fifth boxes, and still fewer or even none to the next adjoining boxes. During the ensuing experimental periods there occurs a regular shifting of the modal point of the distribution of responses nearer and nearer to the correct box. It is as though the animal had aimed its response at a definite point or box in a setting, but because of lack of precision in fine motor adjustment distributed a few of its responses to adjoining boxes. With reinforcement occurring only in a certain constant locus of each setting, the aim of the subject shifted towards it, and with it the distribution of its responses.

Another point of interest in the data that has not been discussed as yet is the fact that most of the curves of learning show that the correct response is adopted more or less suddenly, the curve rising abruptly above the limit of chance expectation. A particularly good example of this is exhibited in figure 4, in which it will be seen that Mamo shifted her response very suddenly from the left-end box (no. 1) to the correct seventh box. The curves of figure 3 show other examples of more or less abrupt

adoptions of the correct response, although in these instances the correct response did not continue immediately to 100 per cent. The interpretation has been made that such sudden adoptions of the correct response are evidence of the occurrence of "insight" or a sudden "seeing into" the problem by the animal. It must be acknowledged, of course, that on the basis of reasoning by analogy with what happens in the case of human subjects when they report that they suddenly "see into" a baffling problem, the behavioral facts are in agreement with this interpretation. In such instances the curve of learning of the human subject does show a sudden jump to solution. There are a number of reasons, however, why the writer believes such an interpretation should be seriously questioned in the present instance, apart from the logical criticism that it is based on anthropomorphic reasoning.

For one thing it will be observed that such sudden shifts also characterized the changes from one wrong response tendency to another. Indeed, the suddenness is to some extent often disguised by the fact that a subject made the change in the middle of an experimental period. There is, then, nothing unique about the sudden adoption of the correct response. Incorrect responses are also adopted abruptly. If one calls these latter erroneous "insights," it is a trifle embarrassing to have to account for their subsequent persistence in an insightful subject.[11] Furthermore, there were many instances in which the subject, having previously suddenly adopted the correct response, subsequently dropped it and shifted abruptly to an incorrect response. The fact that this latter shift was sudden must logically be interpreted to mean that the subject was insightfully abandoning a correct response for an erroneous one. If such behavior is insightful, it is certainly not intelligent.

In a similar manner the present writer would question the

[11] It would seem to the writer that a far better means of distinguishing between insightful and non-insightful behavior would be whether or how long the response was persisted in if correct or incorrect. Persistence in a non-adaptive act is certainly not what is usually understood by insight. The insight writers seem to recognize this criterion in the case of correct or adaptive responses, but ignore it in non-adaptive responses.

interpretation of Yerkes (24) that the generalized type of solution, or as he termed it "discovery," is radically different from the specific type, which he contrasts as resulting from a blind process of trial-and-error.   In the opinion of the writer the evidence of the present investigation does not warrant such a distinction. For, whatever their difference, both types of solution seem to exhibit a considerable number of the phenomena characteristic of what is usually described as trial-and-error, associative learning. In the generalized type the subject's response is to some more abstract aspect of the stimulus, an aspect possibly based upon a common preparatory (perceptual) response to the individual settings.   In the specific type the response seems to be based upon some cue not common to the different settings.   In both solutions, however, the same sequence of trial and abandonment of successive response tendencies until the appropriate one is hit upon, is evident.

IX. SUMMARY AND CONCLUSIONS

This experimental study of the behavioral adaptation of chimpanzees to multiple choice problems was directed primarily towards the analysis of the basis of solution and the nature of the reaction tendencies exhibited prior to solution.   Certain other aspects such as the factors determining the rate of adaptation, transfer effects, etc., have also been studied incidentally.

A preliminary survey of previous experiments in which this type of method had been used indicated that most of the problems had been too difficult for solution even by chimpanzees, so a modification in the direction of greater simplicity was introduced. This consisted chiefly in the use of settings in which the number of boxes was constant instead of variable for a given problem. A modification of the Yerkes-Bingham manual type of multiple choice apparatus was employed for the presentation of the five problems.   In terms of the relation of the correct box to the others in the setting, the problems were as follows: (1) middle box of five boxes; (2) second box from the left end of six boxes; (3) right-end box of seven boxes; (4) left-end box of seven boxes; (5) relearning of middle box of five.   Seventeen chimpanzees

ranging in age from 2 to 22 years served as subjects. All were used in problem 1, eleven were worked in problems 2, 3 and 4, and four in problem 5.

The results and conclusions of the experiment may be summarized briefly as follows:

(1) So far as problem solution is concerned the chimpanzees were very successful. All but two of the seventeen subjects learned the middle-box problem to the criterion of running all 12 trials of an experimental series correctly. The two subjects that failed to meet this criterion would undoubtedly have done so if their training had not been interrupted. Both satisfied a less severe criterion of 20 correct responses in 24 trials. The other problems were solved by all of the subjects to which they were presented.

The middle-box problem proved by far the most difficult of the several problems, with the second-box problem next in order of difficulty, and the end-box problems the easiest. That the relatively great difficulty of the middle-box problem is not to be explained as resulting from the fact that it was presented first is shown by the fact that it still proved to be the most difficult problem for three subjects that learned it after having solved the other problems.

(2) Analysis of the individual learning records of the middle-box problem revealed two different types of learning. Five of the seventeen subjects adopted a generalized mode of solution as shown by the fact that they learned the different settings of boxes more or less simultaneously. The remaining twelve subjects learned each specific setting of boxes separately. Correlated with this difference were the findings of the control trials with novel settings of boxes, which showed that the latter group failed to respond with much more than chance success, while the small group of subjects whose learning record was of the generalized type was successful on 80 per cent or more of the trials.

The learning of problems 2, 3, and 4 was predominantly of the generalized type, the different settings being learned almost simultaneously; and in agreement with this were the results of the various control tests, in which the subjects responded with

high accuracy. That this generalized mode of solution was not the result of the experience gained in learning the middle-box problem was shown by the fact that three subjects that learned problems 2, 3, and 4 before the middle problem also exhibited the generalized method of solution. Furthermore all three subsequently learned the middle-box problem by specific settings.

(3) During the pre-solution period of the first middle-box problem there was little evidence of systematic reaction tendencies to any particular box, the subjects usually choosing the box nearest to them. The pre-solution periods of problems 2, 3 and 4, on the other hand, were marked by a great many instances of systematic reaction tendencies. Indeed, the majority of subjects consistently responded in systematic fashion, shifting in turn from one box to the next until the correct one was learned. Such systematic responses and shifting were also exhibited in a preliminary insoluble series to the second problem. Large and somewhat consistent individual differences were found in the extent to which these systematic reaction tendencies predominated.

(4) In shifting from an incorrect response tendency to the correct box in the learning of problem 2, the subjects did not make a direct shift, but all responded in succession to each of the intervening boxes. In problems 3 and 4, in which the correct box was at the end of a setting, this tendency was much less marked. Only a few responses would be made to the intervening boxes and often they were omitted altogether.

The abandonment of a systematic response to one box and adoption of another were usually accomplished in more or less abrupt fashion, whether the new response was the correct one or not. There were also several instances in which the correct box, having been adopted, was subsequently abandoned for an incorrect box. The embarrassing nature of these results for the "insight" interpretation of sudden jumps in learning is discussed.

(5) There was little evidence of any age differences in the capacity to solve such multiple choice problems. Infant, adolescent, and adult chimpanzees all showed about equal ability. One very important determiner of the speed of solution was the

matter of how near the reaction tendency, which the subject brought to the problem as the result of its past training (previously learned problem), was to the correct response.

(6) Relearning of the middle-box problem by four subjects, after an intervening period in which three different problems were solved, required on the average about one-sixth the number of trials as originally. Error scores showed an even greater saving.

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Color Vision and Color Blindness in Monkeys

WALTER F. GRETHER

From University of Wisconsin and Yale Laboratories of Primate Biology

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COLOR VISION AND COLOR BLINDNESS IN MONKEYS[1]

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CONTENTS

I. HISTORICAL SETTING AND PURPOSE OF EXPERIMENTS

Several color vision theories have offered outlines of the probable evolutionary development of human chromatic vision. Best known is the Ladd-Franklin theory (13) proposing three evolutionary stages: namely, achromatic vision, blue-yellow vision, and blue-green-red vision. McDougall (17) has applied the Ladd-Franklin evolutionary stages to a variation of the Young-Helmholtz theory, and Schenck (19) has borrowed them for a three-component theory which he has offered. Opposed to the

Ladd-Franklin theory is that of Edridge-Green (3). The latter has proposed that color differentiation began with red and violet bands at the two extremes of the spectrum, with additional bands of color appearing until six bands of color were discernible.

Theorization regarding the evolution of color vision has been founded primarily upon data derived from cases of human color blindness. Though the assumption that these human deficiencies are atavistic may ultimately prove valid, there is inadequate support for it at present. Reliable clues to the evolutionary development of chromatic sensitivity should be available in the color vision of man's phylogenetic antecedents. It is probable that some of the developmental stages are preserved relatively unchanged in present-day animals. Data on the color vision of infrahuman animals should aid us in passing judgment on the validity of human color-deficiency data for evolutionary theory.

Numerous experiments on the color vision of mammals other than primates have strongly supported the conclusion that in this entire group of animals color vision is very rudimentary at best.[2] In several studies infraprimate mammals apparently have been trained to discriminate colors widely separated in the spectrum, but the ability has always been much subordinated to brightness vision. Many of the experimenters in this field have concluded, probably erroneously, that their subjects were completely lacking in color discrimination ability. It would seem, from recent experiments by Walton (24, 25, 26), that the usual techniques of conducting brightness control in color vision tests have handicapped mammals with strongly predominating tendencies to react to brightness rather than color differences. In terms of evolution, the color vision of infraprimate mammals can be but little beyond the primitive achromatic stage. Though the vision of this group of animals would therefore seem to hold little information of value for evolutionary theories, we can assume that man's chromatic sense evolved independently of the rather well-developed color vision of certain birds (6, 14), reptiles (31), and fishes (28).

[2] Summaries of the color vision data for mammals are given by Parsons (18); Stagner (20); Warden, Jenkins, and Warner (27); Maier and Schneirla (15); and Washburn (29).

The rudimentary state of color vision among lower mammals suggests that the evolutionary development of human color vision must be sought mainly within the primate order. In table 1 is presented a summary of experimental findings regarding color vision of infrahuman primates. Bierens de Haan and Frima's (2) study of the lemur has indicated that this primitive primate, in common with the lower mammals, has, at best, a very elementary form of color vision. Macaques, on the other hand, as shown particularly by the researches of Trendelenberg and Schmidt (21), have color vision which, within the limits of the tests applied, is equal to that of man.

The experiments of Trendelenberg and Schmidt have provided the only truly quantitative measurements of color vision in infra-human primates. Their subjects were two rhesus monkeys and one Java monkey. A single spectral color was presented on each trial. The subjects were trained to approach and open a food box in response to the positive color, and to remain on a shelf in the cage when any other color was presented. Measured by this technique, discrimination probably was poorer than it would have been had the positive and negative colors been presented simultaneously. Limens were secured in the yellow (589 mμ), green (535 mμ), and blue (490 mμ) regions of the spectrum. In all three spectral regions the discrimination of the Java monkey surpassed that of human subjects tested in a similar manner. The limens of one rhesus monkey were about equal to those of human subjects, while the limens of the second rhesus monkey were somewhat poorer.

Trendelenberg and Schmidt (21) further demonstrated the Java monkey's ability to distinguish a color of 589 mμ from white, and one rhesus monkey's ability to discriminate a color of 520 mμ from white. In a third test the monkey subjects were presented a mixture of red (671 mμ) and green (535 mμ). The monkeys confused the same proportions of this mixture with yellow (589 mμ) as did human beings.

The purpose of the present group of experiments was to analyze the color vision of several different species of monkeys, and to compare these data with similar data for human subjects. In choosing the subjects an attempt was made to secure repre-

TABLE 1
Summary of data on color vision of infrahuman primates

ANIMAL*	COLOR SOURCE	FINDINGS	EXPERIMENTERS
Lemur (Lemur mongoz)	Papers	Color discrimination very poor or entirely absent	Bierens de Haan and Frima (2)
Squirrel monkey (Chrysothrix sciurea)	Papers	Some evidence of color discrimination incidental to study of color relata	Klüver (10)
Cebus monkey	Spectrum	Able to discriminate between red and green, and yellow and blue	Watson (30)
Rhesus monkey (Macacus rhesus)	Papers	Discriminated colors from all shades of gray	Kinnaman (9)
Rhesus monkey	Spectrum	Able to discriminate between red and green, and yellow and blue	Watson (30)
Rhesus monkey (Rhesus macacus)	Spectrum	Color difference limens equal to man's; mixture of red and green responded to as yellow	Trendelenberg and Schmidt (21)
Java monkey (Pithecus fascicularis)	Spectrum	Color difference limens equal to man's; mixture of red and green responded to as yellow	Trendelenberg and Schmidt (21)
Pig-tailed monkey (Nemestrinus nemestrinus L.)	Papers	Discriminated colors from all shades of gray	Bierens de Haan (1)
Chimpanzee	Color wheel	Made relational response to color mixtures independent of brightness	Köhler (11)
Chimpanzee	Colored objects	Matched color samples by hue rather than brightness	Kohts (12). Reviewed in (32)

* The scientific names, where included, are those given by the experimenters. Despite the variations in scientific nomenclature, the rhesus monkeys used in the previous and present investigations were, presumably, of the same species. Java and pig-tailed monkeys are usually included among the genus *Macaca*, although this is not evident from the scientific names given by the experimenters.

4

sentatives of genera differing rather widely in geographical range, habits of life, and taxonomic position.   The choice of the particular animals that were used was dictated by their availability and their adaptability to the laboratory conditions and facilities.

Four different measures of color vision were made: (1) discrimination of wave-length differences at three spectral points, 500 mμ (blue-green), 589 mμ (sodium yellow), and 640 mμ (red); (2) proportion of two colors required in a complementary mixture; (3) visibility curve at the brightness level of the absolute limen; (4) test for dichromatic vision.

II. APPARATUS AND SUBJECTS

Description of apparatus

Two monochromators were used in this investigation to produce spectral colors.   By no other method can colors be obtained that are sufficiently pure, and which are susceptible of gradual changes in wave-length.

The monochromators have been described elsewhere (4, 5). Detailed description will therefore be omitted here, though the essential mechanisms are shown in figures 1 and 2.   White light from a straight filament lamp was resolved into a spectrum by a flint glass prism.   A slit at the plane of focus of the spectrum allowed only the desired wave-lengths to pass through.   Wave-length adjustment was effected by means of a micrometer screw which shifted the position of the source lamp.   Changing the width of the exit slit served as the means of controlling brightness. Behind the slit of each instrument was a mirror to reflect the spectral light down upon either of two food boxes.

Since the earlier published description of the monochromators, two alterations were made which facilitated adjustment of brightness and wave-length of the colors (see figs. 1 and 2).   A geared extension was attached to the micrometer wave-length adjusters to bring the dials below the platform upon which the monochromators rested.   Also, the original slits were replaced by parallelogram-type slits in which both edges moved, and adjustment was by means of levers moving along graduated scales below the

supporting platform. The maximum slit width was $\frac{1}{16}$ of an inch. The scale was graduated from 0 to 10 in half units, so
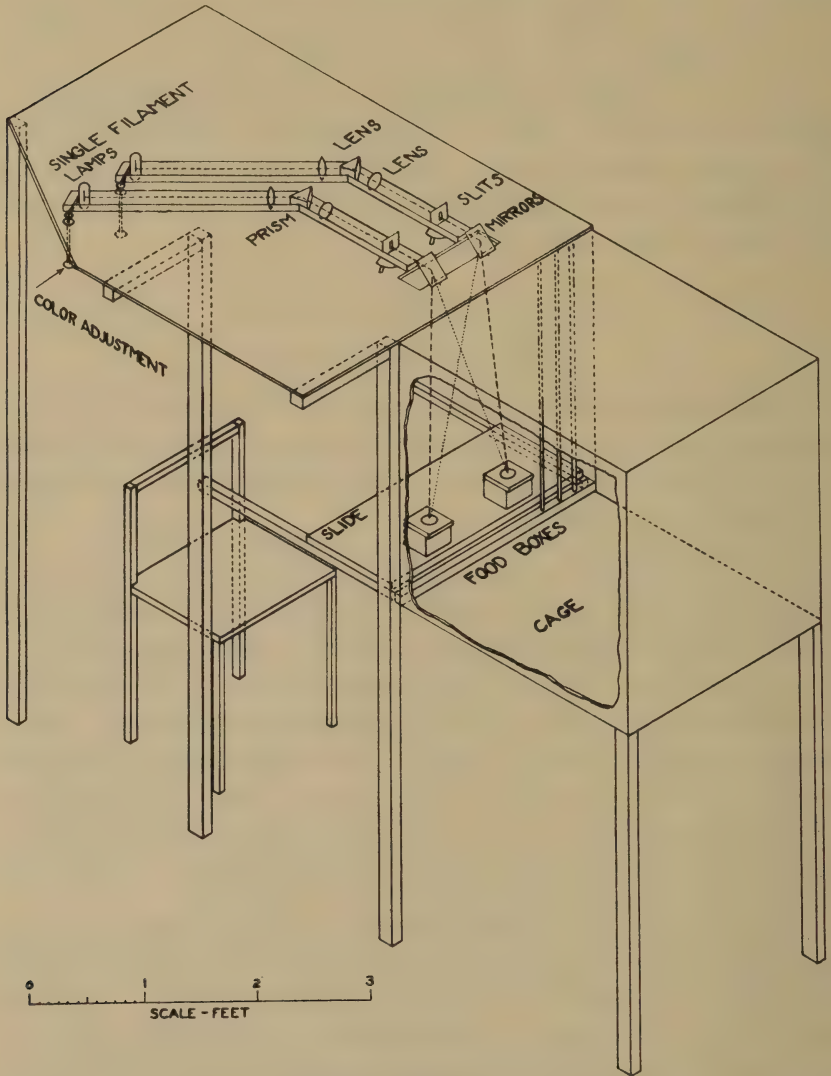
FIG. 1. ISOMETRIC SKETCH OF APPARATUS

that the brightness could be adjusted to 0.00, 0.05, 0.10, 0.15, etc., of the brightness at maximum slit width.

The monochromators were originally calibrated and tested, and later were checked periodically, with the aid of a Hilger constant-deviation spectrometer. With a thermopile and sensitive galvanometer the energy curve of the monochromators at maximum slit width was determined. Also, the brightness of one color, 580 mμ, was photometrically determined by comparison
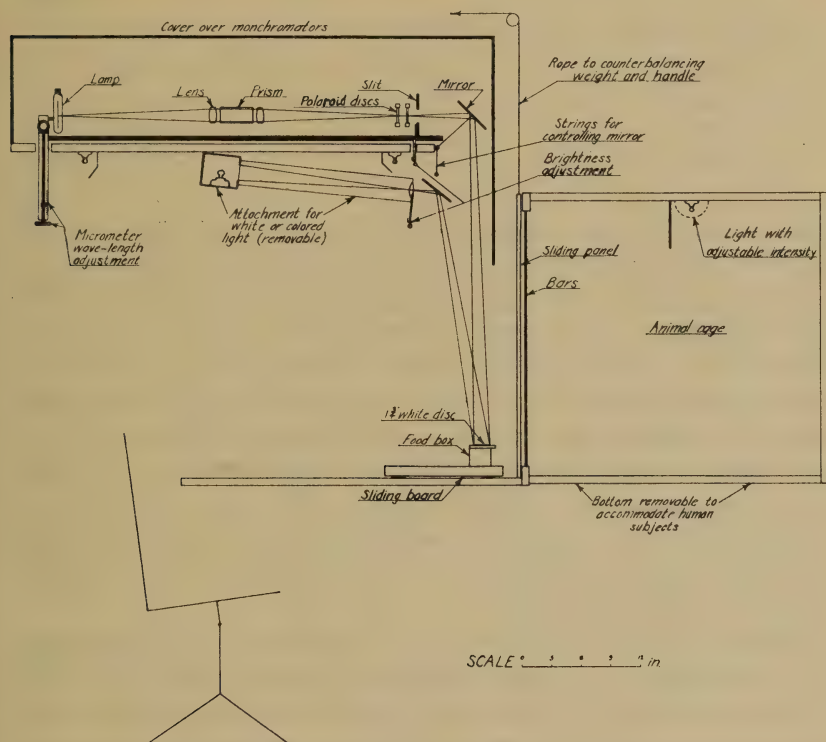
FIG. 2. DIAGRAMMATIC SIDE-VIEW OF APPARATUS

with a standard candle. From these energy and brightness data, and from spectral sensitivity data for the average, light-adapted, human eye (supplied by Walsh, 23), it was possible to construct a brightness curve for the monochromators, giving the illumination of the stimulus patches in foot-candles.

The width of the wave-length band given off by each monochromator varied with the slit width; but since both edges moved

an equal distance, the central wave-length was unaffected by this adjustment.[3] The width of the color band also varied, for a given slit width, with the portion of the spectrum being used. At the spectral points at which difference limens were measured the brightnesses and the widths of the spectral bands were, on the average, as follows:

SPECTRAL POINT	WAVE-LENGTH RANGE	BRIGHTNESS
mμ	*mμ*	*foot-candles*
500	5	0.02
589	3	0.04
640	9	0.04

These are given as average values, since the brightness controls involved changes in both wave-length range and brightness.

Accurate adjustment of the brightness of the colors at very low intensities was not possible merely with the slits of the mono-chromators. For measuring absolute limens this adjustment was supplemented by the use of a pair of polaroid discs placed before the slit as shown in figure 2. With the combination of the polaroid discs and the slit adjustment, fine gradations of bright-ness were possible at liminal values. The discs were mounted in a housing that could be set into the channel iron frame of the monochromators. A pointer on a graduated scale indicated the percentage of transmission.

For the study of complementary color mixtures it was necessary to use supplementary apparatus for projecting white light. This is shown in figure 2. A patch of diffused white light from a

[3] The variations in width of the wave-length band with changes in slit width constituted a disadvantage of this method of brightness adjustment. It is doubtful that the variations in wave-length range resulted in hue shifts comparable in magnitude to those resulting directly from the changes in brightness alone (Bezold-Brücke effect). Furthermore, any adverse effects which the failure to maintain a wave-length band of constant width might have had upon the test results should have been equivalent for all subjects. A constant wave-length range could have been maintained if episcotisters, polaroid discs, or neutral tint filters had been used. But for the present use the advantages of the slit width method in simplicity, convenience, and economy of light transmission were considered to outweigh the aforesaid disadvantage.

Bausch and Lomb microscope substage lamp was focused by a camera lens, and deflected downward to the food boxes by a mirror. An iris diaphragm mounted with the lens provided brightness adjustment. The "daylite" filter in the microscope lamp was removed. The light emitted was therefore the normal output of the electric lamp, slightly yellowish rather than pure white.

The monochromators were mounted upon a wooden platform above the experimenter's position. In this platform were openings through which the brightness and wave-length adjusters projected, and through which the colors were reflected down upon the food boxes. A cover, constructed of brown fiber-board on a wooden frame, completely enclosed the monochromators on the top and sides. This cover, shown schematically in figure 2, had doors on two sides to provide access to the instruments.

The animal cage was enclosed on three sides and the top with brown fiber-board on a wooden frame, and was 24 inches in each of the horizontal dimensions and 26 inches in height. The floor of the cage, built of maple flooring, was fastened in such a way that it could be dropped downward and taken out to facilitate cleaning, or to permit a human subject to be seated in the cage on an ordinary stool set upon the floor of the room. Thus, the human subject had approximately the same view of the stimulus patches as did the animals. On the ceiling of the cage, protected by wire mesh, was a flashlight lamp connected in circuit with a rheostat so that the intensity could be adjusted. As shown in figure 2, a shield between this light and the food boxes prevented the direct rays from reaching the latter. The purpose of this light was to provide a means of gradually adapting some of the more timid animals to the darkness, and to maintain a constant stage of photopic adaptation for the tests in which this was desired.

On the side of the animal cage toward the experimenter there were $\frac{3}{8}$ inch iron bars, placed 2 inches apart, running from the floor to the ceiling of the cage. A strip of $\frac{3}{4}$ inch mesh hardware cloth, fastened across the central 5 bars, prevented the animals from reaching both boxes at the same time. A sliding fiber-board

panel, manipulated by a conveniently placed counterbalancing weight, interrupted the animal's view between trials.

Mounted on a sliding shelf between the experimenter's chair and the animal cage were two food boxes upon which the colored lights were projected. The food boxes, built of a solid block of wood with a hinged cover, were $2\frac{1}{4}$ inches square by 2 inches high. A $1\frac{3}{4}$ inch hole drilled into the top of the block of wood was filled with plaster of Paris in such a manner as to form a rounded depression from which the food could easily be removed after the hinged cover had been lifted. These food boxes were mounted $8\frac{1}{2}$ inches apart (center to center), and in the forward position were 5 inches from the bars of the animal cage. On the cover of each box was a circular patch, $1\frac{3}{4}$ inches in diameter, painted with dull finish white enamel. The remainder of the boxes and the sliding shelf were painted a dull black, so that only the colored light reflected by the white patches was seen by the animals, any stray light falling on the black surfaces being absorbed.

All tests were conducted with the experimental room in total darkness, except for the colored patches on the food boxes and, in the cases where indicated, the light in the animal cage. Lights for making adjustments and recording data between trials were automatically turned on by a mercury switch closed by the sliding panel when in the downward position. This light did not reach the subject, since the animal cage was completely closed when the panel was down.

Subjects

Table 2 presents pertinent data regarding the animals used in this study. All the monkeys were housed in the regular living quarters of the laboratory. Most of them had collars with chains attached, and were led to the experimental room by means of these chains. The spider and cebus monkeys were tamer than the other subjects, and were carried by using their prehensile tails as handles.

To motivate the animals, small pieces of apple, banana, or grape were used as food rewards. The particular fruit used for each animal depended on the individual's preferences. In many

experimental sessions two different fruits were used, since motivation could be maintained at a higher level by such variation in the rewards. The particular foods used as the experimental reward for any animal were omitted from its daily feeding. From 16 to 23 hours always elapsed between the daily feeding and the experimental sessions.

The human subjects were all adult males. Those assumed to have normal color vision showed no deficiency on the Ishihara

TABLE 2

Description of animal subjects

GENUS	SPECIES	COMMON NAME	FAMILIAR NAME	STAGE OF MATURITY	SEX
		New World monkeys			
Cebus......	Unicolor	Cebus	Rufus	Young adult	Male
Cebus......	Capucinus	Cebus	Slit-ear	Young adult	Male
Cebus......	Capucinus	Cebus	Tarzan	Young adult	Male
Ateleus....	Ater	Spider	Joan	Pre-adolescent	Female
		Old World monkeys			
Macaca....	Mulatta	Rhesus	Ben	Adolescent	Male
Macaca....	Mulatta	Rhesus	Bert	Adolescent	Male
Macaca....	Mulatta	Rhesus	Scabby	Pre-adolescent	Male
Macaca....	Mulatta	Rhesus	Tiger	Adolescent	Male
Macaca....	Mulatta	Rhesus	Peggy	Pre-adolescent	Female
Macaca....	Mulatta	Rhesus	Frizz	Pre-adolescent	Female
Macaca....	Nemestrinus	Pig-tailed	Psyche	Adult	Male
Lasiopyga..	Callitrichus	Green	Greenie	Adult	Male
Papio......	Papio	Guinea baboon	Junior	Pre-adolescent	Male

color charts. The other subjects were individuals known to be deficient in color vision. In each case the judgment as to whether their vision was dichromatic, and protanopic or deuteranopic, was determined by the use of the Ishihara color charts and simple tests with spectral colors.

III. DISCRIMINATION OF WAVE-LENGTH DIFFERENCES

Testing technique

Preceding training in discrimination the animals were adapted to the experimental situation and taught to search for food

rewards in the stimulus boxes. From two days to a week were required for this preliminary adaptation period, depending on the subject's previous experiences in other laboratory tests.

A consistent routine was followed on each trial in the discrimination training and all subsequent testing. With the sliding panel down, the positive box was loaded and the mirrors controlling the position of the spectral colors were appropriately adjusted. The panel was then raised, and the animal given an opportunity to open one box. Opening of both boxes was prevented by withdrawing them and lowering the panel before the second one could be reached. Immediate correction for errors was thus prevented. In cases of error, however, the animal was given another choice with the stimuli in the same positions. A trial was not completed until the loaded box had been opened, and regardless of the number of choices of the negative stimulus, the subject was charged with only one error in that trial.

Discrimination training was always begun with yellow (589 mμ) as the positive, and very dim blue-green (500 mμ) as the negative color. After this discrimination had been mastered, the brightness relations were gradually reversed. Unless this reversal of brightnesses disrupted the positive response to yellow, the wave-length of the negative color was then increased by relatively large steps to within about 20 mμ of the positive color. From this point on a gradual approach to the difference limen was made. The limen was arbitrarily defined as the smallest wave-length difference (within 1 mμ) at which an animal met a criterion of 75 per cent correct choices in 25 consecutive trials (within a single session). To find this difference, therefore, the wave-length of the negative color was increased by small steps, and 25 consecutive trials were given on each stimulus pair used. The magnitude of the change at each step depended on the animal's success on the preceding stimulus pair. When performance indicated that a certain color difference was near an animal's limen, further increases in the wave-length of the negative color were made in 1 mμ steps. Testing was discontinued when a difference was reached at which performance dropped below the criterion.

In the usual experimental session 50 trials were given an ani-

mal (25 trials on each of two pairs of stimuli).   At the beginning
of sessions in which discrimination of small wave-length differ-
ences was to be required, a subject was always given 10 practice
trials on a larger color difference.   This procedure gave the ani-
mal an opportunity to readjust to the particular test, and also
gave its eyes an opportunity to adapt to the darkness before
crucial tests were made.   All tests for limens were made with
the experimental room in complete darkness except for the color
stimuli.

In the red region of the spectrum, limens were measured in
the same manner as in the yellow region.   Testing was begun
with red (640 mμ) as the positive, and yellow (usually 589 mμ)
as the negative color.   Training in this discrimination was seldom
necessary.   Evidently the animals had been responding rela-
tionally to the more red of two yellows in the preceding test for
a limen at 589 mμ.

A slight variation of the technique was introduced to obtain
the limens in the blue-green region.   Blue-green (500 mμ) was
used as a stationary negative color, and the changes were made
in the positive color of longer wave-length; i.e., the previous habit
of choosing the more red of two lights was again utilized.   Begin-
ning with the positive color at 589 mμ, its wave-length was
progressively shortened until the limen had been found.   In this
case the limen was the difference between 500 mμ and the next
longest wave-length which the animal could distinguish from it.
This technique eliminated the necessity of setting up an entirely
new color discrimination habit and of working with the increas-
ingly dim spectral colors below 500 mμ.

The technique for testing the human subjects was similar to
that for the animals.   They were given instructions as to which
were the positive and negative stimuli, and were then informed
whether their choice was right or wrong.   For the human sub-
jects the criterion used was 9 correct choices in 10 consecu-
tive trials.

In all the testing, care was taken to eliminate secondary cues.
These controls are discussed below under appropriate headings.
The very fact that performance in every case became poorer as

differences were reduced would seem to indicate that secondary cues were successfully eliminated.

(1) *Brightness controls.* Since the exact sensitivity characteristics of the subjects' eyes were not known, it was impossible to equate with certainty the brightnesses of the two colors. Control of the brightness factor was accomplished by changing the relative brightness of the two colors every 5 trials or oftener. The brightnesses of the two colors were adjusted so that on some trials they appeared equal in brightness to the experimenter, and on other trials the positive color was either markedly dimmer or brighter than the negative color.

(2) *Pattern effects in the lights.* As mentioned earlier, the spectral lights were reflected from white areas on the tops of food boxes. The colors were sufficiently spread out to cover completely the 1¾ inch circular white patches, and light falling around these areas was absorbed by the surrounding black surfaces. Though there was little possibility of cues from irregularities in the shape of the color stimuli, there could have been irregularities in the brightness within the patches that were characteristic of the instruments. No such pattern effects were obvious to the experimenter, but precautions were observed nevertheless. For approximately half of each series of 25 trials, in the study of difference limens, the positive color was supplied by one monochromator, and for the other half it was supplied by the other instrument. This technique served the additional purpose of compensating for any slight errors in calibration of the monochromators which might have escaped the experimenter.

(3) *Other cues.* Precautions were observed to eliminate secondary cues from sounds, odor of food, or expression and movements of the experimenter.

Results

The difference limens for all subjects in the three regions of the spectrum are presented in table 3. The limens are expressed in terms of the wave-length difference, in millimicra, between the central wave-lengths of the positive and negative colors.

Except for the limens of the cebus monkeys in the yellow and

red regions, the limens of the animals and men were quite sharply defined. The increase in errors as the limen was passed was usually quite abrupt. In many cases the animals achieved only chance success when the wave-length difference was 1 mμ less than a difference at which the criterion was met.

TABLE 3

Difference limens at three points in the spectrum for New World monkeys, Old World monkeys, and man

SUBJECT	FAMILIAR NAME	LIMENS AT THREE SPECTRAL POINTS		
		Red 640 mμ*	Yellow 589 mμ*	Blue-green 500 mμ*
		mμ	*mμ*	*mμ*
New World monkeys				
Cebus...............	Rufus	30	4	10
Cebus...............	Slit-ear	45	7	8
Cebus...............	Tarzan	40	8	7
Spider...............	Joan	6	2	10
Old World monkeys				
Rhesus...............	Ben†	8	3	8
Rhesus...............	Bert†	12	2	7
Rhesus...............	Scabby	10	2	8
Rhesus...............	Tiger†	15	4	10
Rhesus...............	Peggy†	12	4	10
Pig-tailed............	Psyche	‡	4	7
Green...............	Greenie	‡	4	‡
Baboon..............	Junior	11	2	9
Human beings (normal vision)............	V. Q.	11	3	6
	L. K.	10	2	21
	C. W.	12	1	12

* In the red and yellow regions the variable colors were of shorter wavelength than the positive colors, 640 mμ and 589 mμ. In the blue-green region the variable color was of longer wave-length than the negative color, 500 mμ.
† Operated animals.
‡ Tests were not made at these points.

No systematic check was made to determine the stability of the limens. Some of the rhesus monkeys included in this study were also subjects in an experiment involving removal of one occipital lobe. Retests of color vision after an operation often resulted in a limen 1 or 2 mμ lower than the original one [see (16)].

Since it is unlikely that the loss of visual cortex was responsible for the improved discrimination, the phenomenon is attributed to additional practice. In table 6 the operated subjects are labeled, and for them the lowest limens are given, most of which were obtained after operations.

In the blue-green region the limens of the human subjects differ quite widely. The 9 out of 10 criterion of success undoubtedly contributed to this result. The 21 mμ limen for subject L. K. is so high that it must be considered atypical, and possibly indicates some color vision defect not revealed by the Ishihara color charts.

Although it was possible to make tests with human subjects viewing the colors from the same vantage point as the animals, it was, nevertheless, impossible to equate perfectly the testing techniques. The animals could be tested only through a training procedure. Any deficiencies of training, motivation, or emotional balance on the part of the monkeys served to handicap them. The advantage of the human subjects was slightly offset by the somewhat more difficult criterion applied to their performance. In view of these difficulties caution must be observed in comparing the human and animal limens. Slightly higher limens for the monkeys are to be expected, and small differences probably have little or no significance.

Conclusions

Examination of table 3 reveals that none of the animals, except the cebus monkeys, had limens which can be considered significantly inferior to those of the human subjects. The limens of the cebus monkeys deserve special consideration, and can probably be compared most profitably with those of the five rhesus monkeys. In the blue-green region of the spectrum the discrimination of these two groups was about equal, but in the yellow and red regions the limens of the cebus monkeys appear to be definitely higher. Statistical evaluation, by Fisher's method, of the differences between the cebus and rhesus limens in the yellow and red regions gives probabilities of 0.97 and 0.99 +, respectively, of true differences.

IV. COMPLEMENTARY COLOR MIXTURES TEST

Testing technique

The complementary color mixtures experiment followed the study of discrimination of wave-length differences, and utilized the response habits already built up in the animals. Discrimination, in this case, was between white light and numerous mixtures of a pair of complementary spectral colors (610 and 495 mμ) supplied by the monochromators. The white light was supplied by the auxiliary projector already described. Since this light was the unfiltered output of an electric lamp, it was slightly yellowish in contrast to sunlight.

Testing was begun with the red light (610 mμ)[4] shining upon the loaded box, and with white light shining upon the empty box. No special training in this habit was necessary since in the previous experiment the animals had chosen the more red of two colors. After 25 trials in which the subject had chosen the red at least 92 per cent of the time, a small amount of blue-green (495 mμ) was added to the red and the latter color reduced by a proportionate amount. Another 25 trials were given with this combination. In this manner the percentage of blue-green in the mixture was gradually increased until a point had been reached where the monkey was choosing the white approximately 50 per cent of the time or oftener. The choice of white more often than of the mixture was evidence that the point of best match between the mixture and white had been passed, and that the mixture now appeared bluish by contrast.

Following the above series of tests in which blue-green was gradually added to red, another series was begun in which red was added to blue-green. Testing was begun with white as the positive and blue-green as the negative color. In this case white was the more reddish of the two colors, and the subjects readily chose the white. Again giving 25 trials at each stage, the proportion of red in the mixture was gradually increased until the subject was choosing the negative stimulus on approximately 50 per cent of the trials.

[4] A wave-length of 610 mμ is called red, though red-orange would be a more accurate description.

In this test the mechanical routine was exactly the same as that for the test of wave-length discrimination and, except for the pattern control, the same precautions were taken to eliminate secondary cues. The outcome of the experiment shows that the animals did not resort to pattern cues, were any such available.

The technique for testing the human subjects with normal vision was somewhat different than for the animals, but presumably gave comparable data. Instead of testing them with all the mixtures that were presented to the animal subjects, numerous mixtures were chosen and presented with white of approximately equal brightness. The subject was asked to state whether the mixture appeared more reddish or more bluish than the white. By this method a proportion of the complementaries was found at which the mixture appeared faintly bluish by contrast, and a slightly different proportion at which the mixture appeared faintly reddish. The proportion midway between these two was taken as the one which most perfectly matched white. It was impossible to get a mixture which the human subjects could not differentiate from white, but the above method of finding the best mixture for human subjects gave very consistent results.

All color mixtures tests were carried out with the light in the experimental cage adjusted to an intensity of $\frac{1}{4}$ candle power. The purpose of the cage illumination was to maintain a comparable stage of visual adaptation in all subjects.

To assist in the analysis of the complementary color mixtures data it was later decided to obtain comparable data on human dichromats of both the protanopic and deuteranopic type. These tests were carried out at the Yale Laboratories of Primate Biology with an apparatus[5] used to study chimpanzee color vision. The subjects themselves were allowed to adjust the brightnesses of the two complementary components and the white to find the best mixture. Determination of whether a subject was actually a dichromat was accomplished by permitting him to search (by adjustment of one of the monochromators) for a spectral color

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[5] This apparatus was essentially a duplicate of the apparatus used at Wisconsin.

which matched white.[6]   The presence of such a neutral point in the blue-green region of the spectrum is evidence of dichromacy. Two subjects were unable to find a spectral color which matched white exactly, but only a spectral region which closely resembled it.   These latter were therefore judged to be incomplete dichromats.   Judgment as to whether a color-blind subject was a protanope or a deuteranope was made by permitting him to match spectral red and yellow in brightness.   A great excess of red in this match was taken as an indication of protanopia; a normal match, of deuteranopia.   This test gave results in agreement with the diagnoses of red-blindness and green-blindness obtained by use of the Ishihara color charts.

Results

The results of the complementary color mixtures test, for the animal subjects, are shown in table 4 in terms of the per cent of correct choices for each mixture that was paired with white. These data were averaged for each of the three genera represented, and the results are presented in the curves of figure 3. It will be noted that the two curves for each genus drop rapidly as they approach a certain mixture and cross, or if extended would cross, near the level of the chance (50 per cent) line.   The drops in the curves indicate that the subjects were having difficulty discriminating between the mixture and white.   The point at which the two curves cross can be taken to indicate the approximate ratio of the complementary colors that gives the best mixture for the particular genus.

Table 5 presents the optimal mixtures for the animals and men with normal vision.   These figures were obtained by plotting individual curves (such as the curves of figure 3) for each animal and taking the point at which the two curves crossed as the optimal mixture.   The optimal mixtures are presented both in the ratio of the slit widths and in the ratio of the brightnesses of the two complementary components.

In figure 3 it is interesting to note that most of the curves dropped

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[6] For determining the neutral point the "daylite" filter was used in the white-light projector.

below the chance line. This may be explained by assuming that the animals were making a choice on the basis of relative color. Speaking in terms of human experience, the animals were probably responding positively to what appeared to be the more red of the two stimulus patches, and negatively to the more blue.

TABLE 4

Summary of data on the complementary color mixtures test for New World and Old World monkeys

COMPLEMENTARY RATIO* (RED/BLUE-GREEN)	CEBUS MONKEYS		RHESUS MONKEYS			BABOON
	Slit-ear	Rufus	Bert†	Tiger†	Frizz	Junior
	Per cent correct in 25 trials (mixture positive)‡					
Pure red	96	92	100	100	100	100
7/3	88	80	100	100	88	100
5/5	76	76	100	100	84	100
4/6	64	60	96	92	88	88
3/7	44	44	88	100	84	96
2.5/7.5			80	96	92	92
2/8			84	40	80	88
1.5/8.5			36		44	64
1/9						48
	(White positive)‡					
3/7	48	52				
2.5/7.5	60	60		26		
2/8	68	88	40	64	52	
1.5/8.5	84	96	68	92	60	48
1/9	84	96	92	96	96	100
Pure blue-green	92	100	96	100	96	96

* The ratio is expressed in terms of the respective brightnesses of the two colors measured in slit width.

† Operated animals.

‡ "Mixture positive" indicates that in this group of tests the mixture was the positive color. "White positive" indicates that in the following tests white was the positive color.

In the discrimination series in which blue-green was being added to red, the mixture was the positive color. But when the proportion of blue-green was greater than necessary to match white, the mixture was the more blue of the two stimuli. It was, therefore, responded to as the negative color, hence the increase in errors beyond 50 per cent. The same principle operated when

red was being added to blue-green, and white was the positive
color.   When the proportion of red in the mixture made it appear
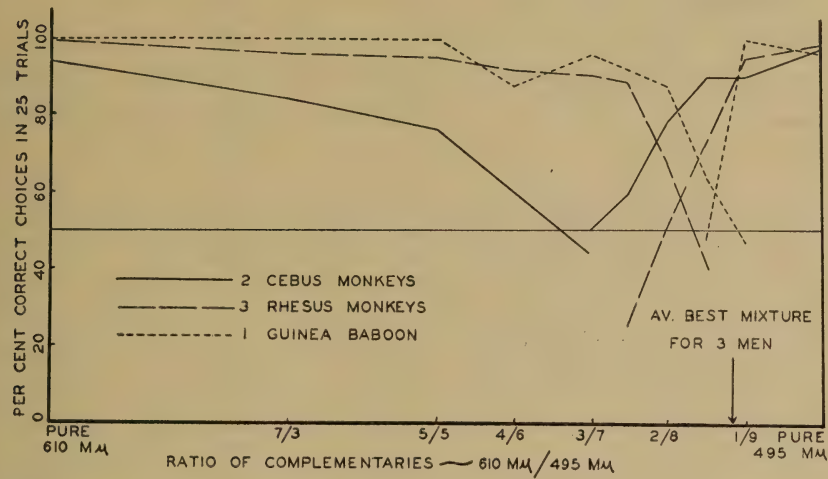
FIG. 3. SUMMARY OF COMPLEMENTARY COLOR MIXTURES DATA SHOWING DIS-
CRIMINATION CURVES FOR THREE GROUPS OF MONKEYS
    The ratio of complementaries is given in terms of slit widths of the respective
monochromators.

TABLE 5

*Optimal complementary color mixtures for New World monkeys, Old World monkeys,
and man*

SUBJECTS	OPTIMAL MIXTURES	
	Ratio of slit widths (red/blue-green)	Ratio of foot-candles* (red/blue-green)
Cebus (Slit-ear).........................	0.450	4.50
Cebus (Rufus)..........................	0.472	4.72
Rhesus (Bert)†..........................	0.205	2.05
Rhesus (Tiger)†.........................	0.266	2.66
Rhesus (Frizz).........................	0.205	2.05
Baboon (Junior).......................	0.163	1.63
Man (V. Q.)...........................	0.111	1.11
Man (L. K.)...........................	0.111	1.11
Man (C. W.)...........................	0.159	1.59

* For the same slit width the red was ten times as bright as the blue-green.
† Operated animals.

more red than the white, the animal began responding to it
positively, and therefore made more than 50 per cent errors.

TABLE 6

Complementary color mixtures data for color-blind men

TYPE OF COLOR BLINDNESS	SUBJECT	NEUTRAL POINT	RATIO OF RED TO BLUE-GREEN IN MIXTURES*	MEAN RATIO FOR FOUR MIXTURES
		$m\mu$		
Protanopia (red-blind)	D. H.	512	2.73 3.33 5.71 4.44	4.05
	R. W.	504	8.00 7.50 6.98 5.45	6.98
	J. M.	503	2.22 2.50 1.50 4.29	2.63
	E. R.	498	3.64 4.00 4.29 3.87	3.95
	F. S.	508	2.00 2.22 2.35 1.50	2.02
Deuteranopia (green-blind)	G. H.	535†	2.31 2.07 2.00 2.14	2.13
	H. B.	540†	2.00 1.56 1.56 1.56	1.67
	A. P.	510	1.76 1.61 1.05 1.25	1.42
	H. S.	500	1.67 2.00 1.77 1.50	1.73

* This ratio is based upon brightnesses of the colors in foot-candles.

† For these subjects there was no region which exactly matched white. The wave-length given for the neutral point therefore represents only a color which most closely resembled white. These subjects apparently were not complete dichromats.

22

In table 6 are shown the data for the color-blind men.   Each subject made four adjustments of the complementary mixture to match it with white.   In order to demonstrate the lack of precision in the mixtures the results are given for each matching. This lack of precision was obviously a result of the deficient hue discrimination of these individuals.

Conclusions

The comparative performance of the animals and the men with normal color vision is clearly shown in figure 3 and table 5.   All the animals, it will be noted, required a slightly more reddish mixture than did the human subjects.   Compared to the average for the three men, the additional amount of red required in the mixture was 32 per cent for a Guinea baboon, 79 per cent (average) for three rhesus monkeys, and 270 per cent (average) for two cebus monkeys.   Statistical analysis yields a probability of 0.98 that the difference between rhesus monkeys and men is reliable, and a probability of 0.99 + for the difference between cebus monkeys and men.

In general, the mixtures of the protanopes resemble those of the cebus monkeys, and the mixtures of the deuteranopes, those of the other subjects; but this relationship is not consistent for all cases of dichromacy.

V. VISIBILITY CURVE AT THE LEVEL OF THE ABSOLUTE LIMEN

Testing technique

Absolute limens were measured by using only one spectral color and requiring the subjects to choose the lighted box.   Testing was begun at the red end of the spectrum with the color fairly bright.   Without special training the animals chose the red box in preference to the dark one, again a result of the previous training.   The brightness of the color was then reduced rapidly until the subjects showed signs of difficulty in discriminating.   Then, giving 25 trials at each point, the brightness was gradually reduced until performance failed to meet a criterion of 75 per cent or more correct choices in 25 trials.   Limens were thus measured at 20 mμ intervals down to a wave-length of 440 mμ.

The procedure on each trial was the same as that used in the test of wave-length discrimination. Control of pattern and brightness cues was unnecessary, but the usual precautions were taken to eliminate other secondary cues.

Brightness adjustment in this test was by the combined use of the monochromator slits and the polaroid discs, each of which cut down the brightness at maximum slit width by a known and controllable percentage.

In order to measure the limens at a constant level of photopic rather than scotopic adaptation, the lamp in the ceiling of the animal cage was maintained at a constant intensity of $\frac{1}{4}$ candle power. This illumination was assumed to raise the visual adaptation above the scotopic level, since the colors of colored surfaces were clearly visible in the cage under this illumination.

The human subjects were tested under the same conditions as the animals. However, a 9 out of 10 criterion was used as in the measurement of difference limens.

Results

The absolute limens were measured in terms of the per cent of maximum brightness for the particular color (brightness at maximum slit width). These percentages were then converted into energy values from the energy curve of the monochromator. Table 6 presents these limens in terms of energy reflected from the surfaces of the food boxes.

From the data presented in table 7 the curves of figure 4 were constructed by computing the reciprocals of the limens and then mathematically equating the area under the curves of these reciprocals. Figure 4 therefore gives what can be called equal-area, equal-energy visibility curves. The purpose in equating the areas was to bring the curves nearer together for easier comparison. Had this not been done, the curve for the cebus monkeys would have been so much lower than the other two curves that any differences in form would have been much more difficult to perceive.

The curves of figure 4 exhibit one striking feature not at all typical of visibility curves. A dip, instead of a peak, appears

in the central region of the spectrum for all subjects. This atypical phenomenon can be accounted for by the conditions under which the absolute limens were measured. Although the food boxes were shielded from the direct light of the adapting lamp in the ceiling of the cage, some of this light did, by reflection from the cage walls, reach the stimulus surfaces on the covers of the boxes. A color which resembled the adapting light, as yellow certainly must have for the human subjects, was therefore dis-

TABLE 7

Absolute limens of subjects at various spectral points

WAVE-LENGTH	LIMENS IN ERGS/SQ.CM./SEC. REFLECTED FROM SURFACES OF FOOD BOXES					
	Cebus monkeys		Rhesus monkey	Men		
	Slit-ear	Rufus	Tiger*	L. K.	V. Q.	C. W.
$m\mu$						
700	6.9	2.1	1.1	0.62	0.78	0.13
680	3.9	1.4	0.23	0.25	0.21	0.033
660	0.20	0.35	0.13	0.053	0.071	0.014
640	0.17	0.090	0.037	0.036	0.042	0.0060
620	0.18	0.070	0.025	0.030	0.010	0.0050
600	0.10	0.060	0.060	0.012	0.012	0.0080
580	0.057	0.080	0.064	0.026	0.038	0.016
560	0.20	0.11	0.060	0.0072	0.029	0.0048
540	0.20	0.11	0.047	0.0057	0.017	0.0019
520	0.068	0.11	0.035	0.0098	0.011	0.0028
500	0.16	0.13	0.032	0.0037	0.016	0.0028
480	0.14	0.11	0.028	0.0089	0.017	0.0017
460	0.19	0.13	0.029	0.0058	0.026	0.0092
440	0.24	0.20	0.034	0.024	0.032	0.018

* Operated animal.

tinguished with greater difficulty at liminal intensities than other colors more unlike the adapting light. The curve for the human subjects dips lowest at 580 mμ, which is in the spectral region most resembling a low intensity electric light in color. This explanation presupposes that a color difference served as a partial cue for the subjects. This presupposition was subsequently verified for the human subjects by questioning them regarding the appearance of the liminal lights. For this reason the curves of figure 4 are of questionable value for their intended purpose as

visibility curves. Even though this color cue had been avoided, the visibility curves would have compared the sensitivity of the subjects at an extremely low level of brightness. Failure to find interspecies differences at the brightness level of the absolute limen would not have excluded the possibility of differences in spectral sensitivity at higher intensities. On the other hand, the
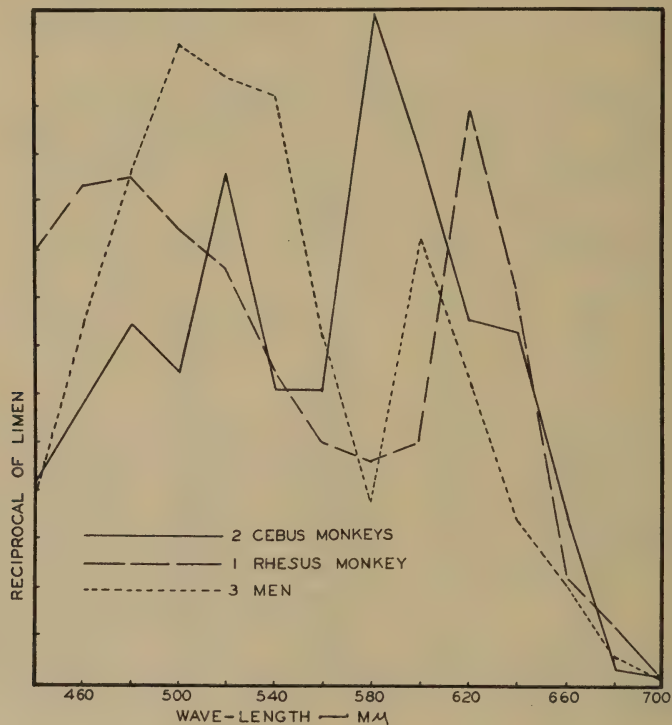

FIG. 4. EQUAL-AREA, EQUAL-ENERGY VISIBILITY CURVES PLOTTED FROM RECIPROCALS OF ABSOLUTE LIMENS

curves provide a rather important datum in showing which spectral region most resembled a low intensity electric lamp in color for the animals.

Conclusions

The visibility curves fail to reveal any differences among the three groups of subjects in relative sensitivity to different regions

of the spectrum.   Because of failings in the experimental method, however, we cannot safely draw the conclusion that such differences in spectral sensitivity did not exist.

An unexpected finding is revealed by the dips in the visibility curves.   For cebus monkeys the region of the spectrum resembling the color of a low intensity electric lamp was at least 20 mμ nearer the short wave-length end of the spectrum than for the rhesus monkey and the men.

It will be noted in table 6 that the absolute limens of the human subjects average considerably lower than those of the animals. Furthermore, the limens of the cebus monkeys are significantly higher than those of the rhesus monkey.   Just what these differences mean is not clear from the available data.   Since hue apparently served as an important cue in this test, it is quite possible that the absolute limens provide a measure of the cone thresholds of the several subjects.   This would indicate that the cone thresholds are lowest for man, somewhat higher for rhesus monkeys, and considerably higher for cebus monkeys.

VI. TEST FOR DICHROMATIC VISION[7]

After completion of the previous experiments it appeared desirable to check the possibility that the vision of the cebus monkey subjects was dichromatic.   The spectrum of a dichromat should, theoretically, contain a colorless band in the neighborhood of 500 mμ.   Since this has been demonstrated adequately for human beings with dichromatic vision, a test for such a neutral band should be a crucial test of dichromacy in an animal.

Testing technique

The test for a neutral band in the spectrum was carried out by checking an animal's ability to discriminate between white and spectral colors between 600 and 480 mμ.   Since the animals were already trained to choose the more reddish of two stimuli, the tests were begun with 600 mμ as the spectral color and positive stimulus.   The transition to shorter wave-lengths was then made

[7] The test for dichromatic vision was conducted by G. Buettner after the author had left the University of Wisconsin.

in 10 mμ steps. White light was supplied by the projector used
for the complementary color mixtures study, but in this case the
tests were made both with and without the "daylite" filter in
the lamp. For this test the cage light was again used, at an
intensity of $\frac{1}{4}$ candle power. The spectral colors were at approx-
imately the same brightnesses as were used for the measurement
of difference limens. Precautions to eliminate secondary cues
were observed as usual.

Results

Only one of the cebus monkeys, Rufus, was still alive at the
time this test was carried out. As a control subject a rhesus
monkey, Tiger, was tested in the same manner. The findings
are presented in table 8 in the per cent of correct choices at each
spectral point. Although 50 trials were given at most points,
figures are given for the last 25 trials only since these most accu-
rately reflect the animals' discrimination after preliminary adjust-
ment to each new color. It will be noted that the cebus monkey
discriminated with merely chance success between 520 mμ and
510 mμ, and white. At 500 mμ this animal reversed his habit
and quite consistently chose the white. To continue the testing
at shorter wave-lengths, therefore, white was used as the positive
color, as indicated in the table. No such breakdown and reversal
of discrimination occurred for the rhesus monkey. There can be
little doubt that for the cebus monkey the portion of the spectrum
from 510 to 520 mμ was a colorless or neutral band, comparable
to the neutral region typically found in human dichromacy.

The reversal of the cebus monkey's discrimination habit at
colors below 510 mμ is susceptible to the same explanation as was
given for the partial reversals in the color mixtures experiment,
namely, that discrimination was on a relational basis and that
the relation between the spectral color and white was reversed
for colors below the neutral point. The reversal did not occur
for the rhesus monkey because for it there was no neutral point.

An unexpected finding in this test was that the neutral band
was apparently unchanged in wave-length when the "daylite"
filter was omitted. For the human being there is a marked color

difference between the "daylite" white and the yellowish white of an electric lamp because of the greater quantity of long wave-lengths in the latter. If the cebus monkey's sensitivity to red was reduced, however, as the color mixtures data suggest, it was relatively less sensitive to the red and yellow wave-lengths cut out by the "daylite" filter. For this reason the color difference between the two whites was probably much less for this animal than for man.

TABLE 8

Results of test for dichromatic vision

WAVE-LENGTH	PER CENT CORRECT CHOICES IN 25 TRIALS		
	Cebus (Rufus)		Rhesus (Tiger)† "Daylite" filter
	"Daylite" filter	No filter	
600	100	100	100
590	100	100	100
580	100	100	100
570	100	100	100
560	100	100	100
550	100	100	100
540	100	100	100
530	100	100	100
520	52	68	100
510	56	52	100
500	100*	84	100
490	100*	100*	100
480	100*		100

* On these trials white rather than the spectral color was used as the positive stimulus.

† Operated animal.

Conclusions

The presence of a neutral band in the blue-green region of the spectrum of the one cebus monkey justifies the conclusion that the color vision of this animal was dichromatic.

VII. DISCUSSION OF RESULTS

Comparison of Old World monkeys and man

(1) *Macaca mulatta.* In discrimination of wave-length dif-ferences the rhesus monkeys did not differ significantly from the

human subjects. In the visibility curve study also, the one curve for a rhesus monkey does not differ reliably, in form or in position of the dip, from the human curve. On the other hand, rhesus monkeys required significantly more red in a complementary color mixture for it to match white than did three human subjects. The latter result indicated that for these monkeys the particular red (610 mμ) was either relatively less saturated (in comparison with the blue-green, 495 mμ), or relatively lower in brightness. Possibly both differences contributed in producing the result.

(2) *Macaca nemestrinus.* The one pig-tailed monkey that was tested achieved difference limens equal to those of rhesus monkeys in the yellow and blue-green regions of the spectrum.

(3) *Lasiopyga callitrichus.* One green monkey was tested only for a limen in the yellow region of the spectrum. This limen was in the same range as those of rhesus monkeys.

(4) *Papio papio.* Both in difference limens and complementary color mixtures the one Guinea baboon compared favorably with the human subjects. The optimal complementary mixture for the baboon resembled the human optimal mixture more than did that for any of the other monkeys. Because of baboons' predominantly terrestrial habits, their color vision might be expected to be inferior to that of more arboreal monkeys. That such cannot be the case seems to be indicated by the high development of color vision in the one specimen of genus *Papio.*

Comparison of New World monkeys with other subjects

The New World (platyrrhine) monkeys differ considerably in structure, habits, and taxonomic position from the Old World (catarrhine) monkeys. For this reason a comparison of these two groups is particularly important.

(1) *Cebus capucinus and Cebus unicolor.* The cebus monkeys were shown to differ from the other subjects in that (*a*) the difference limens were higher in the red and yellow regions of the spectrum, (*b*) a much larger proportion of red was required in a complementary mixture, (*c*) the spectral region resembling undifferentiated yellowish light was shifted at least 20 mμ toward the

shorter wave-lengths, and (*d*) dichromatic vision was indicated by a neutral band in the spectrum at 510 to 520 mμ.   The meaning of these differences will be discussed more fully in a later section.

(*2*) *Ateleus ater*.   One spider monkey was tested for difference limens at three points in the spectrum.   Unfortunately, this animal was not available when the other tests were carried out. Since spider and cebus monkeys are members of the same family, we should expect their visual capacities to be quite similar.   This, however, appears to be an entirely false expectation.   The spider monkey possessed excellent discrimination at all three spectral points, the limens in the red and yellow regions being exceptionally low.

It seems safe to conclude from the data of the one specimen of *Ateleus ater* that the deficient color vision of cebus monkeys is not a general characteristic of South American primates.

Comparison of results with those of previous investigators

The data of the present study corroborate the conclusions of Kinnaman (9), Watson (30), Bierens de Haan (1), and Trendelenberg and Schmidt (21) that macaques are capable of making color discriminations.   Watson's (30) finding that cebus monkeys can discriminate colors is likewise verified.

Difference limens measured in this study cannot be compared directly with those reported by Trendelenberg and Schmidt (21) for macaques because of differences in experimental methods. However, in comparison with human subjects used as the standard of comparison, their animals did about equally well.   The present findings support their conclusion that in color discrimination ability macaques do not differ significantly from human beings.

Trendelenberg and Schmidt (21) found that macaques responded to a certain mixture of red and green as to yellow, as do human beings.   From this finding they concluded that the monkeys possessed trichromatic vision no different from that of human beings.   This conclusion is in mild disagreement with the present finding that rhesus monkeys require slightly more red in a com-

plementary mixture than do human beings. The two experiments are, however, not directly comparable since the German investigators used a mixture which produced yellow, rather than a complementary mixture, and their test method was less sensitive than that used in the present study.

The evidence for dichromacy of cebus monkeys

The test for dichromacy was carried out with only one cebus monkey. In the other measures, however, there was a high degree of consistency among the subjects, indicating a fundamental similarity in their visual systems. If the vision of the cebus monkey, Rufus, was truly dichromatic, as the test indicated, it is highly probable that the same was true for the other cebus subjects, Tarzan and Slit-ear. In fact, the difference limens of the latter two animals were higher than those of Rufus in the yellow and red regions of the spectrum, indicating that their visual deficiencies were as great or greater.

All of the findings for the cebus monkeys are consistent with the conclusion that their vision was dichromatic. The hue discrimination data are similar to those of Hecht and Shlaer (7) for three human dichromats. In the central region of the spectrum the discrimination of the dichromats was about equal to that of a normal trichromat, but at either end of this region the difference limens became very high. The range of approximately normal discrimination was from about 480 to 550 mμ, with considerable individual variability. At 589 mμ the deficiency of the human dichromats was much more marked than that of the cebus monkeys under consideration, but the results are similar in that the limens in the yellow and red regions were significantly raised. Apparently the chief difference is that the abrupt rise in limens was nearer the red end of the spectrum in the case of the cebus monkeys. For this difference there is a logical explanation in that the neutral point for the one cebus monkey was about 20 mμ nearer the red end of the spectrum than the neutral points of the dichromats tested by Hecht and Shlaer.

The location of the dip in the visibility curve for cebus monkeys at 540 to 560 mμ is consistent with a conclusion that their vision

was dichromatic.   Hecht and Shlaer (8) have demonstrated for human dichromats that from either side of the neutral point to the ends of the spectrum, hue discrimination is based merely upon saturation.   To a dichromat, therefore, a spectral color about 540 to 560 mμ in wave-length would resemble white with some red added, which was also the color of the dim adapting light in the experimental cage.

The much greater proportion of red required in the complementary mixture by cebus monkeys indicated either relatively reduced saturation or reduced brightness of this color (610 mμ). In either type of dichromacy it is quite probable that red is reduced in saturation, but this condition is more likely to exist for a blue-green of wave-length 495 mμ since it is much nearer the neutral point.   For this reason it is more probable that the overabundance of red in the cebus mixture indicated reduced sensitivity to this color, a condition associated with protanopic vision.

Unfortunately, the data for cebus monkeys provide no direct proof of whether or not sensitivity to red was reduced.   The visibility curves do not provide dependable information concerning sensitivity at photopic brightnesses.   In an attempt to answer the question of whether the vision of the cebus monkeys conformed to human protanopia or deuteranopia, the complementary mixtures data for human dichromats was secured.   It can be seen by a comparison of tables 5 and 6 that four of the five protanopes used as much or more red in some of their mixtures as there was in the optimal mixture for cebus monkeys. When shown the cebus mixture the fifth protanope (F. S.) correctly stated that it appeared more "yellowish" than the comparison white.   However, this protanope did tolerate more red in the mixture than do subjects with normal vision.   On the other hand, none of the deuteranopes required as much red in the mixture as did the cebus monkeys.   Except for the one dissenting case, the complementary mixtures of the protanopes resembled those of the cebus monkeys, and the mixtures of the deuteranopes, those of the other monkeys and the men with normal vision.   A conclusion that the color blindness of the cebus monkeys conformed to human protanopia is therefore supported.

Even though the present data indicate dichromacy of the protanopic type in the three male cebus monkeys which were tested, a generalization that two-color vision is a characteristic of the genus *Cebus* is hardly justified by such a small sampling. The present findings should be supplemented by tests of other cebus monkeys, preferably of different species and of both sexes. The possibility of the color blindness being limited to the male sex is suggested by the excellent color vision of the New World spider monkey, a female, and the fact that color blindness is virtually limited to males among human beings. A more complete analysis of the color vision deficiency of cebus monkeys would also be desirable.

Significance of results for evolutionary theories of color vision

Findings of the present study which have possible significance for evolutionary theories of color vision are: (*a*) dichromacy, apparently of the protanopic type, in cebus monkeys, (*b*) slightly lowered effectiveness of red in a complementary mixture for rhesus monkeys.

We have in these discoveries a suggestion that cebus and rhesus monkeys might represent successive stages in the evolutionary development of human color vision. We can never do more than assume this to be true, however, since these monkeys are not in the direct line of human ancestry. Still, such an assumption would seem to be at least as justifiable as the one that human color blindness represents atavistic stages in color vision evolution. In the present case there is no conflict between the two assumptions. The findings for cebus monkeys are a valuable supplement to human color blindness data in that they suggest that protanopia rather than deuteranopia was an evolutionary antecedent to trichromatic vision.

In so far as the present results indicate dichromacy in cebus monkeys, they provide the first evidence for the existence of a blue-yellow stage of vision in any infrahuman mammal.[8] The

[8] Obviously it is impossible ever to determine the subjective quality of an animal's color sensations, but it is generally assumed that the two colors seen by a human dichromat are blue and yellow.

evidence for a two-color stage of vision in cebus monkeys clearly lends substantial support to the Ladd-Franklin (13) evolutionary theory, and the related theories of Schenck (19) and McDougall (17).   However, to harmonize the apparently protanopic vision of cebus monkeys with the Ladd-Franklin theory a slight revision would seem necessary.   The differentiation of yellow into red and green would have to be assumed to be asymmetrical.

It is possible, also, to interpret the lowered effectiveness of red (610 mμ) in a complementary color mixture for rhesus monkeys on the basis of the Ladd-Franklin evolutionary stages.   If we suppose that in these animals the red-green differentiation (third stage of the theory) is less complete than in man, there are two possible deductions to account for the color mixture results. First, if this differentiation involved an increase in sensitivity to red, as the findings for cebus monkeys suggest, we would expect the sensitivity to red to be lower for rhesus monkeys than for man. Second, if the less complete differentiation of red and green involved a greater overlapping of the spectral regions to which the respective receptor mechanisms were sensitive, we would expect a red of 610 mμ to be reduced in saturation.

The findings of the present investigation both oppose and favor the Edridge-Green (3) theory of color vision evolution, which posits development of color sensations first at the two extremes of the spectrum.   In the case of both the cebus and rhesus monkeys there was evidence that their vision for the red end of the spectrum had not reached the human level of development.   The results therefore suggest that vision in the red end of the spectrum was the last rather than the first to develop.   On the other hand, the finding of a neutral band near the center of the spectrum for one cebus monkey is in agreement with this theory.

VIII. SUMMARY AND CONCLUSIONS

The aim of the present investigation was to compare the color vision of several species of New World and Old World monkeys with that of human beings.   Such an analysis is important for evaluating evolutionary theories of human color vision.

By projecting spectral colors upon two food boxes, and training

the animals to associate food rewards with color stimuli, four measures of color vision were made: discrimination of wave-length differences, proportion of two colors necessary in a complementary mixture, visibility curve, and test for dichromatic vision. Human and monkey subjects were tested under conditions as nearly identical as possible.

Results of the experiments can be summarized as follows:

1. Wave-length discrimination of Old World monkeys (a Guinea baboon, a green monkey, a pig-tailed monkey, and five rhesus monkeys) did not differ significantly from that of human beings. Discrimination of three New World cebus monkeys was significantly poorer in the red and yellow regions and about equal in the blue-green region. The discrimination of a New World spider monkey was equal to that of the Old World monkeys.

2. Compared to the average for three men, all animals tested required a greater proportion of red in a complementary mixture for it to match white. The additional amount of red required was 32 per cent for a Guinea baboon, 79 per cent (average) for three rhesus monkeys, and 270 per cent (average) for two cebus monkeys.

3. Visibility curves derived from absolute brightness limens showed no apparent differences in spectral sensitivity among a rhesus monkey, two cebus monkeys, and three men, but these results are of questionable value as a comparison of spectral sensitivity at higher brightness levels.

4. A test for dichromatic vision, given one cebus monkey, revealed a neutral band in the spectrum at 510 to 520 mμ. This result was taken to indicate that this animal, and probably the other two cebus monkeys also, had dichromatic vision.

5. Comparison of the color mixture data for cebus monkeys with similar data for human dichromats supported a conclusion that the color blindness of the cebus monkeys conformed to human protanopia (red-blindness).

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DELAYED REWARD IN DISCRIMINATION LEARNING BY CHIMPANZEES[1]

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I. INTRODUCTION

A. Delayed reward in animal learning

The inadequacy of cues lacking constant spatial settings for animal learning with delayed reward is a general fact which has received almost no recognition. The typical delayed reward problem, of which Watson's (1917) may be considered the proto-type, is spatial. The usual animal maze is analogous in that it also is spatial and involves the temporal separation between the behavior to be learned and the attainment of reward. The mere temporal delay after an animal reaches the place at which the food is received is found to have little or no effect on the rate of learning in spatial problems (Watson, 1917; Carr, 1919; Warden and Haas, 1927). When the amount of time for pre-goal activity varies, on the other hand, a direct relation between the length of such an activity period and the time required for learning is found (Clements, 1928; Hamilton, 1929; Roberts, 1930; Wilson, 1934).

The moment that visual stimuli are made independent of a positional context, delayed reward becomes ineffective for learning. Experimenters who have come upon this inadequacy have not seemed to recognize its generality. Examples to be found in the literature have reached print only as incidental observations in conjunction with reports of "positive" findings secured in other directions or after modifications of procedure. Helson (1927) has made one contribution in exception of this general indifference. Finding that rats failed to discriminate grays when food was put some distance beyond the place of "choice" in the discrimination box, Helson concludes:

> The point to be noted here is that when there is absolutely no insight, *when the conditions of chance are actually imposed upon the animals,*

no learning at all takes place. Subsequent pleasure does not retroact to stamp in the correct initial act. . . . (p. 392).

Wolfe (1934) attempted to train white rats in a black-white discrimination with an enforced delay between "choice" and the food or no-food consequence. Practice under these conditions resulted only in the formation of position habits. A change was instituted, so that the animal was made to return to the choice point immediately following wrong responses until a correct response had been made. Under this condition, which provided an immediate differential consequence following behavior at the choice point, the discriminative act was established. Wood (1933) studied the effects of delayed reward and delayed punishment on the formation of brightness discrimination habits. Again the successful technique provided differential consequences temporally adjacent to the choice-response. All shock-delay groups were given food immediately in the event of a "correct" response, and food-delay groups were shocked immediately after a "wrong" response.

The inadequacy of temporally removed consequences for the establishment of discriminative responses to non-positional cues is further confirmed by work with trace conditioning. Differential conditioning becomes difficult or impossible when an appreciable interval is permitted to elapse between the stimulus to be conditioned and the elicitation of the conditioned response. Speaking of this characteristic, Pavlov (1927, p. 113) says: "The trace reflexes . . . exhibit a permanent and universal generalization. . . ." And concerning attempts at differential extinction:

. . . there is this striking fact, that in the case of trace reflexes following the application of various stimuli, which of course are never reinforced, the effect of the special conditioned stimulus to which the trace reflex was experimentally established also becomes temporarily diminished, and the secretion may fall to zero . . . (p. 116).

B. *Spatial vs. non-spatial delayed response*

Demonstrations of the difference in the efficacy of spatial and non-spatial stimuli are to be found in studies of delayed

response. Delayed response techniques have shown that birds, rats, cats, dogs, raccoons, and the primates respond selectively on the basis of a single presentation to locations which have been designated by food or a food-surrogate. (Reviews of the literature may be found in Tinklepaugh, 1932, and Washburn, 1936.) The marked facility for such spatial differentiation by chimpanzees is attested to by acuity of locational discrimination, resistance of the response to distraction by irrelevant activity, and the length of delays successfully negotiated (Yerkes and Yerkes, 1928; Tinklepaugh, 1932).

The separation of visually presented cues from fixed positional contexts has been effected in attempts to secure non-positional delayed response with anthropoid apes. Kohts (1923) reports that her chimpanzee was able to match samples of colored woolens only if the choice was made within 15 seconds after the showing of the original sample. Yerkes (1928), in work with the gorilla Congo, used a turntable for presenting food boxes differing in color, size, and markings. This animal's performance on non-positional delayed response was perhaps more successful than any other's yet reported. Congo selected one from among six boxes after delays of from 2 to 10 minutes, with correct choices on 80 per cent of the last 25 among the 108 trials given. Yerkes and Yerkes (1928) tested chimpanzees with differently colored boxes. Only one of four chimpanzees gave any indication of ability to utilize the colors mnemonically. A series of attempts to secure non-spatial delayed response in young chimpanzees is described by Nissen, Riesen, and Nowlis (1938), and supports the general conclusion that the problem is a very difficult one. Even after subjects had undergone extensive pre-training, only relatively short delays were negotiated. Delayed alternation to non-positional cues (Nissen and Taylor, 1939) was accomplished by one chimpanzee with an accuracy of at least 76 per cent when two boxes differed in size, color, form, and opening device. Elimination of the difference in color had no adverse effect on performance, whereas removal of the difference in opening device produced a considerable drop in score. In consideration of the possibility that more experienced animals might find readier modes of adaptation to the visual non-spatial de-

layed response problem, Yerkes and Nissen (1939) tested 19 adult and 5 adolescent chimpanzees with the choice between a white and a black box, one of which was baited, prior to a minimal delay, in full view of the animal subject. They conclude: "In our findings we consider most significant the evidence that delayed response, in the absence of spatial cues or with misleading cues, is either extremely difficult or impossible for most chimpanzees."

The traditional treatment of delayed response failed to consider it a learning problem. More recent experimental attacks have taken as a point of departure the hypothesis that delayed response and discrimination learning can be distinguished as two learning situations differing (1) in the rate of response-acquisition, and (2) in the manner of reinforcement by direct as opposed to signaled reward (Nissen, Riesen, and Nowlis, 1938). Cowles (1940) has demonstrated gradations in the degree of retention of positional delayed responses under three pre-delay (practice) conditions, and suggests that discrimination learning may be included on an extension of the same scale of difficulty. It is apparent that spatial and non-spatial stimuli possess markedly different degrees of effectiveness for learning in infrahuman primates. Such a conclusion finds confirmation in a consideration of the rate of animal adaptation in traditional discrimination learning problems, which utilize immediate reward. It is only after many contiguous presentations of the non-spatial stimulus and the reward that correct choices become significantly more numerous than incorrect ones. The primates appear to have no advantage over many lower forms in learning simple visual discriminations.[2] Such protracted learning periods are in sharp contrast to the immediacy and accuracy of discrimination between positional cues.

[2] The comparison between monkeys and apes and lower forms is stated in a review by Spence (1937, p. 807):

Thus the early experimental studies of Kinnaman, Shepherd, Watson, and Johnson with monkeys, and Köhler with chimpanzees, showed that these animals learned discrimination habits in much the same manner as the lower forms, such as, the white rat, dog, and chicken. The presolution period was usually marked by a more or less prolonged series of repetitive errors and successes until finally the response was made consistently to the correct stimulus.

C. Hypotheses with regard to learning with spatial and non-spatial cues

To account for the inadequacy of non-spatial stimuli as cues in delayed response and in learning by delayed reward, the same set of assumptions can be made. The first of these assumptions is that for associative learning to take place, the stimulus and the response to be associated must both be accompanied by the reward. This principle denies the possibility of learning when reward is delayed *unless* surrogates or replicas of the stimuli and the responses are either carried by the organism through the period of delay or are somehow reinstated when reward occurs. The second assumption is that animals, unless specially trained, do not react to a non-spatial stimulus in such a way as to provide the necessary surrogate or replica. That is to say, "intermediate reactions" (Hilgard and Marquis, 1940, Chap. X) do not ordinarily occur to non-spatial cues. Such reactions have apparently never been conditioned during the life span of most animals. Thus, laboratory findings in delayed response tests to color suggest that no reaction *specific to a given color* occurs when reward is signaled. The third assumption is that self-stimulation from intermediate or implicit representative reactions has the unique property of entering into single-trial associations. In other words, responses which occur during such stimulation are associated with it to such a degree and specificity that they will function upon the next recurrence of the stimulation. According to this hypothesis, tests of delayed response fail (to color, for example) when intermediate reactions are not present to provide the self-stimulation essential for single-trial learning. A detailed exposition of the stimulus-reaction relations assumed for delayed response and for learning with delayed reward will be reserved for the discussion, following a description of the present experiment.

With respect to learning by delayed reward, Thorndike (1932, p. 451) has stated the generalization which is in agreement with the above assumptions as follows: "Nobody has ever demonstrated a case where a satisfier has strengthened a connection remote from it in time. . . ." In concluding the report of an

experimental attack on the problem of the efficacy of immediate vs. remote after-effects, Lorge and Thorndike (1935, pp. 193–194) state that:

Very much more decisive results statistically could be obtained by experiments using more available and definable responses, such as tapping keys, saying words or numbers, *etc.*, but it is almost impossible to prevent human subjects from keeping a connection ending in such a response in mind until the after-effect occurs or from recalling it to mind when the after-effect occurs and then repeating some equivalent of the after-effect. The real relation would then be immediate, regardless of how long an ostensible delay we used.

Under the presumption that chimpanzees are not ordinarily able to "keep in mind" colors or color names, an experimental investigation of the validity of the hypotheses suggested above was undertaken. The subjects were divided into two categories, to provide, first, the control tests without established surrogate-reactions and, second, the tests after special training which might provide symbolic reactions[3] to colors.

II. DESCRIPTION OF EXPERIMENT

A. Apparatus

The discrimination apparatus (fig. 1) permitted the presentation of two colors in adjacent stimulus-windows. Stimuli were derived from filtered transmitted light. A red, green, or neutral (gray) stimulus could be presented in either window. During preliminary adaptation, while the subjects learned to operate the apparatus, both stimulus-windows were gray. The subject learned to use one hand for pressing one of the two button-blocks (*a*) located directly over the stimuli, while the other hand pulled down the overhead lever (*b*). The stimulus-surface

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[3] The term "symbolic reaction" is used in the present discussion to designate a concept similar to the "idea" or "representative process" of Hunter (1913), the "movement-produced stimulus" of Washburn (1916), or the "pure stimulus act" of Hull (1930). There is much to be said in favor of the term "intermediate reaction" used by Hilgard and Marquis (1940) in a similar sense. As these authors point out, the earlier terms are severely encumbered by complex and vague connotations.
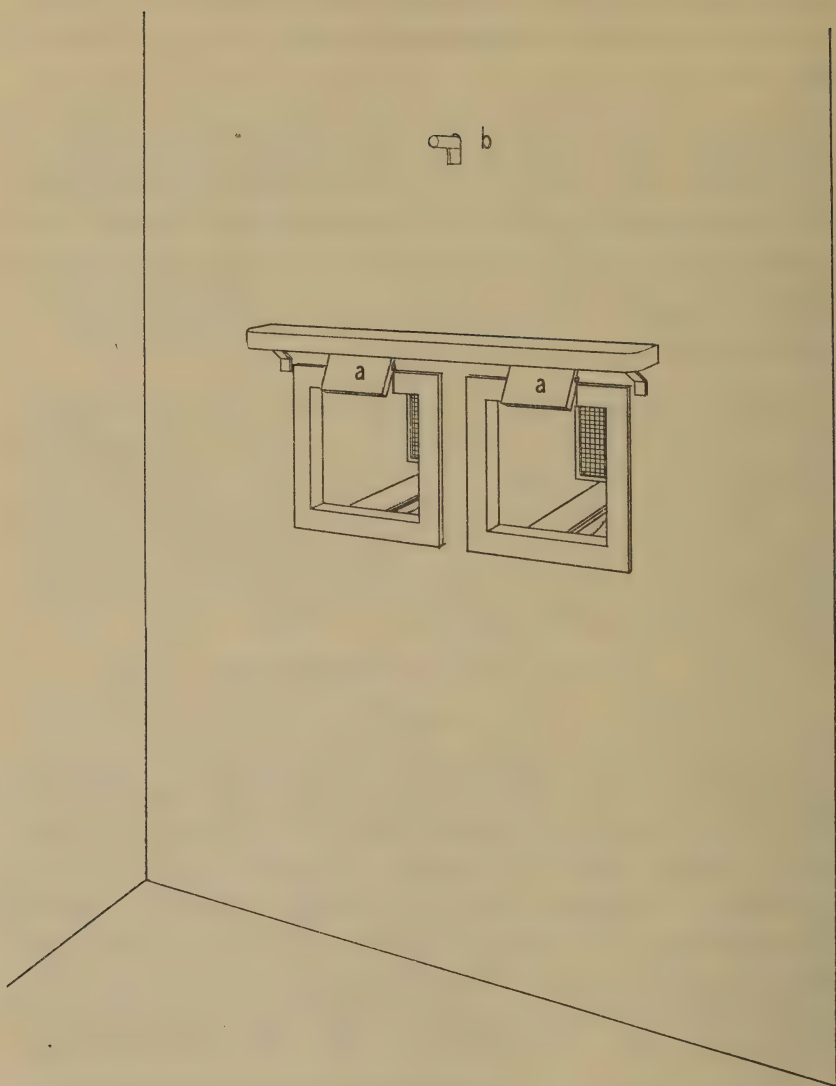
Fig. 1. The Discrimination Learning Apparatus

Showing the stimulus windows with button-blocks, *a*, and the overhead lever, *b*. Both stimulus-carriers have been pulled back, revealing the food-wells at the bottom of the open food compartments.

beneath the block against which the animal pushed moved away from the subject at a slow uniform rate for a distance of 20.5 cm. The excursion required 10 seconds, and depended upon the functioning of an electric clutch which delivered power from a synchronous motor whenever the subject's bimanual response completed the electrical circuit. A sharp click of the food-delivery mechanism coincided with the end of the excursion, whether food was delivered or not. On "correct" trials the reward, a slice of orange of approximately 9 grams, dropped from a trap-door into the food-compartment opened by the excursion of the stimulus-carrier.

For the non-delay or immediate reward condition, the stimuli remained on until 2 seconds after completion of the excursion. For work with delayed reward the transmitted light in each stimulus-window turned off at a given interval before completion of the excursion. The expanding food compartment was dimly lighted from within as soon as the color stimuli disappeared.

A pull of 500 grams was required to close the electrical contact at the overhead lever. A pressure of 200 grams sufficed to operate either choice-button. The lever was 94 cm. and the buttons were 67 cm. above the floor of the room.

The apparatus was designed to conform as nearly as possible to the procedural desiderata listed:

1. *Accurate control of the temporal sequence.* (1) Choice response by subject; (2) disappearance of stimuli; (3) delay; (4) reward or non-reward.

The time intervals were accurately controlled by a gear mechanism driven by a Bodine synchronous electric motor (type NSY-12 RH, $\frac{1}{75}$ h.p., 1800 r.p.m., with a 60 to 1 heavy duty worm gear reduction).

2. *Provision for varying the delay interval to make possible the investigation of learning rate as a function of the length of the delay.* Except for especially long delays (subject Hal), which were provided by changing the ratios of the sprockets used in the chain drive, delay intervals were controlled by parallel settings along calibrated scales mounted on each stimulus-carrier (fig. 2).
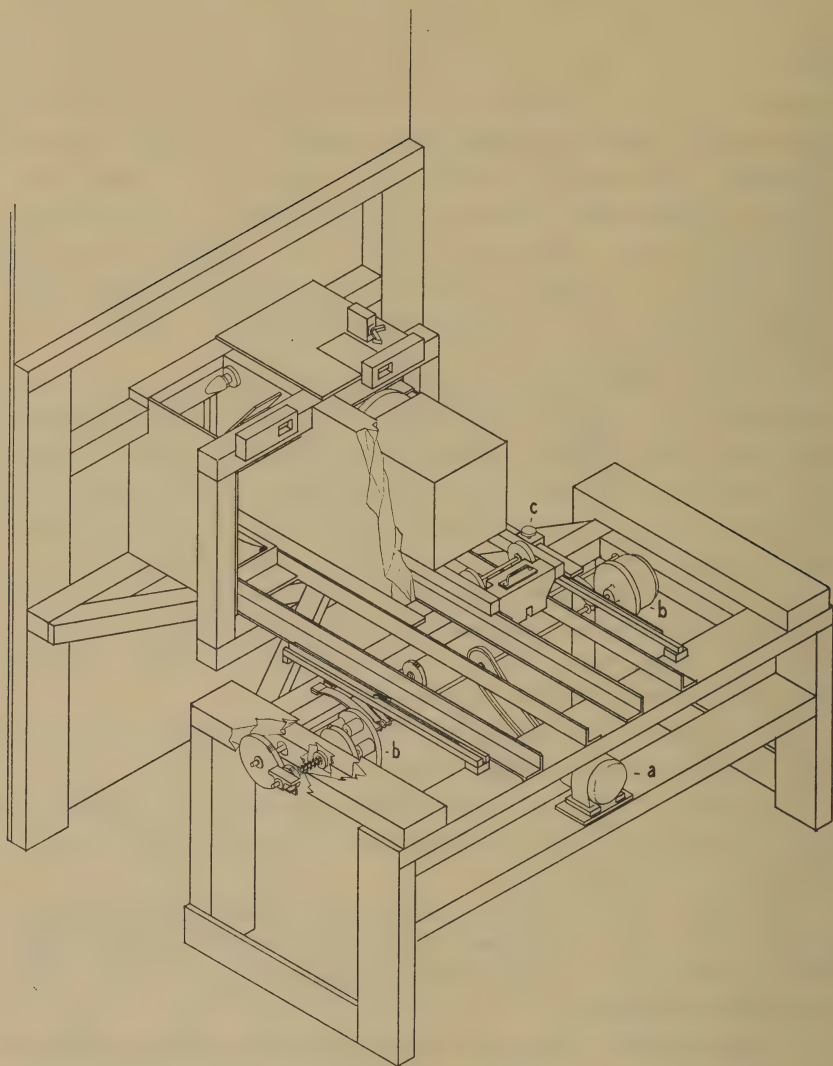
FIG. 2. THE DISCRIMINATION LEARNING APPARATUS AS SEEN FROM THE EXPERI-
MENTER'S COMPARTMENT, SHOWING THE MECHANISM FOR INTERVAL CONTROL
One stimulus-carrier has been removed.　Power from the synchronous motor,
a, was transmitted to either stimulus carrier by the operation of the correspond-
ing electric clutch, *b*.　Electrical contacts, *c*, functioned automatically during
the excursion of either stimulus-carrier to determine the interval between cue-
disappearance and reward or non-reward.

These settings determined the point of disappearance of the colors during the excursion of either stimulus-carrier.

3. *Control of the subject's activity, with respect to amount and direction, during the interval between the initial choice and the occurrence of the goal response (obtaining of the reward).* The object of this provision was to free the subject as much as possible from variable distractions on learning tests with intervals of different durations. The use of both hands by the chimpanzee insured a fairly high degree of constancy in his motor adjustment. The bimanual adjustment was maintained throughout the excursion-period during every trial. A sound-shielded dark-room was used for the experiment to minimize distracting stimulation. The only light in the experiment room at the start of a trial came from the colored stimulus patches and from a small point of light marking the base of the overhead lever.

4. *Equalization of the frustration of delay.* Since the same subjects were to be given repeated tests for learning capacity with various periods of delay of reward, a decrement in motivation was to have been expected if the time between choice and the termination of delay were raised above that of the previously completed test.[4] This factor would have operated against learning with delayed reward to make ambiguous the variable under investigation; namely, stimulus and reward separation. A constant interval for response was maintained throughout all tests, with the exception of a special series on Hal, in order to offset this effect. Every trial, whether non-delay or with delays of 1, 2, 4, or 8 seconds, required 10 seconds between response at one or the other window and delivery or non-delivery of the reward.

In figure 2 an isometric drawing of the apparatus is reproduced. Power was transmitted by a roller chain from the synchronous motor (*a*) to a drive shaft, on either end of which an electric clutch was mounted. The clutch magnets pulled a disc, firmly mounted on a short shaft, against the heads of each of the six magnets comprising the clutch, thus locking the shafts together.

[4] Such an expectation is implied in a recent systematization of the theory of behavior related to frustration (Dollard, et al., 1939).

The short shaft was connected by gears and via a third shaft to
the rack mounted beneath the stimulus-carrier. In order to
prevent motion of the stimulus-carriers, if pushed directly, the
clutches were made to operate against the action of coil springs,
which served to lock the systems beyond the drive shaft when
no current passed through the clutch. The coil spring held the
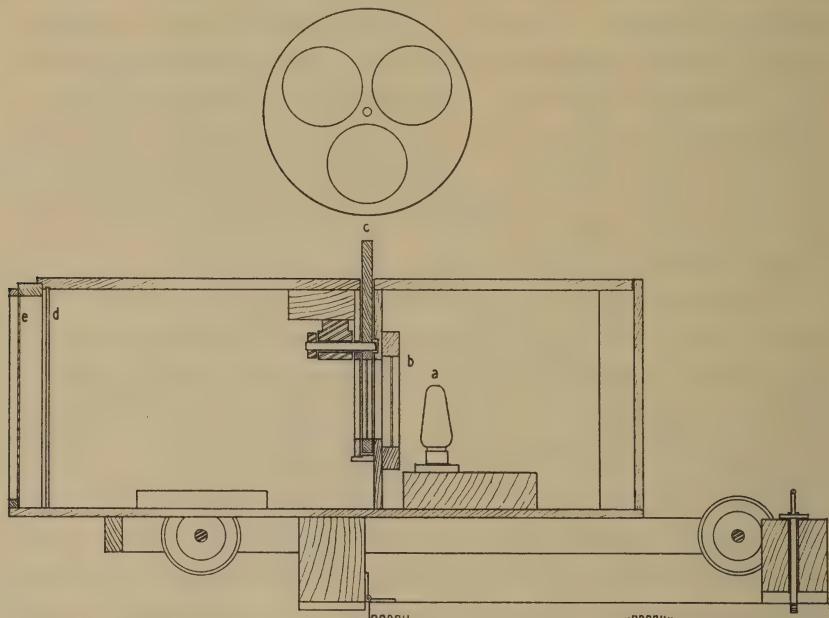
FIG. 3. ONE OF THE STIMULUS-CARRIERS SHOWN IN CROSS SECTION, SIDE VIEW
a, the light source; b, plate glass for reducing heat at Wratten filter; c, filter-
disc for interchanging the stimulus colors; d, flashed opal glass—the stimulus
surface; e, wire mesh shield.

short shaft and disc away from the clutch magnets, and at the
same time pushed the teeth of the small gear on the outer end
of the shaft into grooves cut in an angle iron bolted to the ad-
jacent bearing.

Flanged wheels on the stimulus-carriers permitted them to
roll along angle-iron tracks. The rear aspect of the left stimulus-
carrier, as it stands forward in position for response, is shown in
the figure. The handle situated just back of the axle and wheels

permitted the experimenter to raise the rack, against light spring pressure, and free it from the gear below. The experimenter could then return the carrier to the forward position after a trial.

One of the stimulus-carriers is shown in cross section in figure 3. Candelabra type lamps (7 w., 110 v.) served as the light source. After passing through a plate glass, which served for heat reduction, the light was filtered by one of three Wratten filters. These filters (Wratten nos. 29, 63, and 96) were quickly interchangeable by rotation of the filter-disc. The filters transmitted red, green, or neutral light, which passed through the forward chamber of the carriage to illuminate the heavy flashed opal glass plate. This plate served as the stimulus-surface, a square 15 cm. on a side, and was shielded from the hands of the subject by a wire mesh screen having 4 squares to the running inch. Calibration with a photo-sensitive cell (Weston illumination meter, model 603) showed the green and neutral stimuli to be approximately 0.15 millilamberts and the red stimulus about 0.20 millilamberts in brightness, after corrections for the difference between the human visibility curve and the cell response were made.

B. General procedure

Preliminary adaptation. As a means of establishing the habit of pressing and maintaining the pressure on a button, pretraining was given the chimpanzee subjects on a simple food-vender. Initial settings of this device allowed the delivery of food immediately upon the application of pressure against a button-block similar to the choice-blocks of the regular apparatus. As the habit progressed, the subjects were required to hold the block down for a brief time. They were then shifted to the regular apparatus. The lever-controlled portion of the clutch circuit was at first short-circuited, so that button pressure alone sufficed to produce movement of the stimulus-carriers. Neutral stimuli were presented in both windows during the course of acquisition of the manual operations required in the response. At first the carriers were both set near the tripping point so that the excursion time was only a second or two. As rapidly as the subject learned to maintain relatively persistent pressure, this

distance was increased until the entire 10-second excursion was achieved as an uninterrupted movement.

In order to establish the habit of using the lever, one or the other of the contacts controlled by the buttons was short-circuited, and, except in the cases of two subjects who quickly learned in its absence, a shield was placed over the buttons. The action of the lever was demonstrated by the experimenter until the subject began its manipulation. Then followed the combining of lever and button operation. The experimenter at first assisted in the completion of this combination as the subject used one or the other of the mechanisms. As soon as the chimpanzee learned to respond with both hands, the experimenter remained in his separate section of the room behind the apparatus. With exceptions in the case of Don which will be indicated below, the subject was alone during the regular learning trials.

Discrimination learning. The training of all subjects in discrimination responses to the red or the green cue was first carried through without delay of the reward, for the purpose of measuring learning rate under this condition. During the learning of three habits by each subject, the stimulus colors remained on until 2 seconds after the click of the trapdoor. An orange slice of 9 grams was used as the reward in all tests, both with immediate and delayed reward procedures. The criterion of learning was response to the experimentally correct color in 18 of the 20 trials within a single session. Two sessions, one morning and one afternoon, were carried through daily with each subject. The eight orders used for the presentation of the correct stimulus with respect to the two stimulus-compartments were designed to meet the following criteria:

1. The first and second 10 trials of each session contained 5 right and 5 left positions for the positive cue.

2. At least 2 rights and 2 lefts appeared in each quarter (5-trial group) of a session.

3. No more than 3 rights or 3 lefts occurred in succession.

4. On 10 trials of the 20 the colors changed from the position occupied by them on the previous trial.

When a subject had learned an initial color discrimination (to green, for example), training to the other color (i.e., red) was begun, again under conditions of immediate reward. Learning of this habit is an example of what will be called a habit "reversal." Finally, a second reversal, or third discrimination habit (i.e., to green) was trained. Tests of learning with delayed reward were then begun.

Four intervals of delay, 1, 2, 4, and 8 seconds, were used in the main series of learning tests with delayed reward. Tests with each delay-interval were balanced as far as possible, first, with respect to the color that was rewarded for learning on successive tests with the same interval, and second, with respect to the different delays used on the tests immediately preceding those with a given interval. A test was considered complete when consistent response (90 per cent or more within a session) to the rewarded cue was achieved, or when 600 trials had been completed without indications of performance significantly better than chance.

In the case of failure on a given test, training in the habit whose establishment was being attempted was continued with a shorter delay until the criterion of learning was achieved. This provision was necessary in order that the succeeding test might start as a "reversal" on a par with other tests.

Further details of the procedure and the special training given the subjects in the experimental group will be described in connection with the results.

C. Subjects

Control group. The subjects in the control experiment were two male chimpanzees, both born at the Southern (Orange Park, Florida) Division of the Yale Laboratories of Primate Biology, and transferred to New Haven on June 23, 1937. Their acquaintance with the present experimenter began at that time. The dates of their birth, the periods of work in the present experiment, and their weights at the beginning of experimentation are given in table 1. The previous experimental history of these subjects included no training in visual discrimination.

During the period of the present investigation, both subjects were being used in a study of factors determining social preferences. Dick was also serving in a work-method study of differential incentives. No interference, motivational or otherwise, was ever observed between the concurrent investigations.

Experimental group. Dick, who had first served as a control, and three additional subjects comprised the special training group. As can be seen from the table, animals both older and younger than either of the controls were included. All were

TABLE 1

NAME	NUM-BER	SEX	BIRTH-DATE	PERIOD OF EXPERI-MENTATION	WEIGHT
Control subjects					
					kg.
Dick................	37	M	7/15/33	6/24/38– 3/ 9/39	18
Don*................	39	M	5/ 2/34	6/23/38– 2/16/39	17
Experimental subjects					
Beta................	52	F	10/31/31	6/23/38–11/ 3/38	23
Tom................	33	M	6/26/33	7/29/38–10/17/38	23
Dick................	37	M	7/15/33	4/25/39– 6/ 6/39	20
Hal................	43	M	10/ 7/35	7/ 6/38– 2/28/39	13

* Castrated February 27, 1936.

born at the Southern Division of the Laboratories and complete experimental histories were thus available. Beta had served in a study of non-positional delayed response, utilizing brightness stimuli (Nissen, Riesen, and Nowlis, 1938). The results in the present study gave no evidence that she had an advantage over the other three subjects by reason of this previous experience. Tom and Hal had learned visual discriminations at one time, but under conditions of immediate reward such as were in effect during the learning of the first three discrimination habits by the control subjects.

The limiting dates only are given under the periods of experimentation. Hal was absent from the experimental situation

from November 23, 1938 to January 19, 1939, to permit the measurement of retention. During the present investigation, Tom was also serving in the two concurrently performed studies for which Dick was a subject.

III. RESULTS

A. Control subjects

Preliminary adaptation. Dick and Don learned the use of the button on the preliminary training apparatus during the course of a few sessions. After a little further training, maintenance of pressure against the button superseded an initial tendency to poke at it. Don was never fully at ease during the first week or so, and would usually begin to whimper after a few trials, then stop working and beg to be picked up. He apparently disliked being away from his cage-mates.

When first introduced to the regular delayed reward apparatus, Dick and Don were both timid. Adaptation was retarded because Don exhibited emotional disturbance at being left alone in the subject's section of the experiment room. The presence of another experimenter with Don was temporarily resorted to, in order first to habituate the animal to the routine of the procedure. Dick was fearful of touching the buttons for about 10 days. In the course of several weeks, however, both subjects mastered the choice-button response, and were maintaining pressure continuously for the required 10 seconds.

Introduction of the lever-pulling requirement was the next step. The buttons were covered with a shield, and by turns one or the other of their contacts was short-circuited. Demonstration of the lever-action by the experimenter soon brought response to it on the part of Don. After an additional session during which he secured food by using only the lever, the shield was removed and the combined response made necessary. Don worked hard trying to secure movement of the carrier by shifting from one button to the other and up to the lever, successively. Help was occasionally extended by the experimenter in order to complete the circuit. In two sessions the bimanual action with lever and button was learned. Throughout the

course of the experiment Don used his left hand on the lever
when pressing the right button with the right hand, and the right
hand on the lever for the choice of the left button.

For many days Dick failed to do more than touch the metal
lever very lightly with his finger tips. Even this degree of ap-
proach finally dropped out, and only on those trials (or sessions)
during which, for the sake of encouragement, the button-re-
sponse alone was made sufficient did he secure the orange. Since
it seemed that he was avoiding the lever, a means of overcoming
this difficulty was sought. Tying a rope to the end of the lever
brought about no improvement, but when a strip of burlap was
attached, response was immediate. Burlap-pulling plus button-

TABLE 2

*Showing trials, errors, and position preferences (if any) for three color discrimination
habits under the immediate reward condition*

HABIT	DICK				DON			
	Num-ber trials	Errors	R choices	L choices	Num-ber trials	Errors	R choices	L choices
Red.....................	100	55	63	37	80	20	52	28
Green...................	180	109	101	79	60	26	36	24
Red.....................	180	69	69	111	60	23	31	29
Average...............	153	78	78	76	67	23	40	27

pressing responses rapidly developed. Successive shortening of
the burlap until it was just long enough to afford a firm grasp
completed the preliminary adaptation. This subject continued
to work throughout the experiment with the burlap attachment,
which he always pulled with his left hand, leaving the right
free for use on either button.

Discrimination learning with immediate reward. Table 2 gives
the number of trials, number of errors, and the positions of the
choices by the two subjects during the learning of the three
habits with immediate reward. Scores in all cases include the
errors and trials of the session in which the criterion of 18 cor-
rect in 20 was met. Dick averaged 153 trials for learning to the
criterion. Don required an average of only 67 trials. The

average number of errors during the course of learning was 78 and 23, respectively.

The general nature of these results does not differ markedly from data obtained with animals on other types of apparatus. Color discriminations have been learned by chimpanzees at roughly the same rate when the animals pushed directly against the colored stimulus cards (Nissen and McCulloch, 1937).

Discrimination learning with delayed reward. When the stimulus colors did not remain visible until the moment of reward, the learning problem proved to be of a very different order of

TABLE 3

Number of trials, errors, and position responses for color discrimination habits under varying conditions of reward-delay

Subject Dick

HABIT	DELAY	NUMBER TRIALS	ERRORS	RIGHT CHOICES	LEFT CHOICES
	seconds				
1. Green......................	1	380	195	313	67
2. Red........................	2	520	226	336	184
3a. Green.....................	4	600*	326	367	233
3b. Green.....................	1	160	58	86	74
4a. Red.......................	4	600*	297	345	255
4b. Red.......................	2	80	14	50	30

* Failure.

difficulty. The data are summarized for subject Dick in table 3. The first test with this subject was made with a 1-second delay. On every trial both colors disappeared simultaneously just 1 second prior to the click of the food-delivery mechanism, whereupon the appearance or absence of food indicated success or failure. The number of trials required for criterion-learning more than doubled, by comparison with the average for learning without delay of reward. Trials increased by 148 per cent, and the error-increase was 150 per cent. When the delay was advanced to 2 seconds for the next test, learning was further retarded. The number of trials (520) represents an increase of 240 per cent over the immediate reward average. When a 4-

second delay interval was used, the problem became too difficult, performance remaining at a chance level through 600 training trials. Following this failure the delay interval was reduced to 1 second, and the habit was learned in 160 additional trials, 58 of which were error-trials. Again a test was made at the 4-second interval, this time with the other color (red) as the rewarded stimulus. After 600 trials without solution, the reversal was completed by training under the 2-second delay condition.

That Dick did learn something during the 600 trials of training with 4-second delays is indicated by the lesser time required for completion of these habits after delay reduction, as compared with initial results at the shorter delay intervals. This is in part accounted for by the early dropping away of the previously learned response, which would be expected because of the absence of reward, regardless of the length of the delay interval. That is, the anticipatory or reward "expectancy" reactions were necessarily thwarted during the early trials of each habit-reversal, and according to the theoretical constructs to be outlined further in the final discussion, both the incipient "expectancy" reactions and the overt choice-response to one or the other color are considered to have been eliminated.

In addition to this "forgetting" of the previous habit, it is probable that the stimulus had not become entirely ineffective at the end of a 4-second period, and learning might eventually have been evidenced with continued practice. Such is the interpretation placed upon the data which are graphically presented in figure 4. A very gradual reduction in the percentage of errors occurred during the course of the 600 training trials. The green and the red habits were developed to 55 and 58 per cent accuracy, respectively, by the final 100 trials.

Proof of the fact that learning is still possible with a delay of reward of 4 seconds was afforded by the outcome of Don's first delayed reward test. The results for this subject are presented in table 4. Learning of a habit to green was achieved after a training period of 420 trials. This represents an increase of 527 per cent over the average score on immediate reward for this subject, which is a very substantial increase in relative

difficulty over the habits learned at delays of 1 and 2 seconds by Dick, whose general learning rate was considerably below that of Don.

During the test at 4 seconds, behavior appeared which proved later to have been a sign of trouble. Restless activity, whimpering, and other signs of impatience occurred during many experimental sessions. There was an extreme increase in the preference for the right stimulus-window. During five sessions
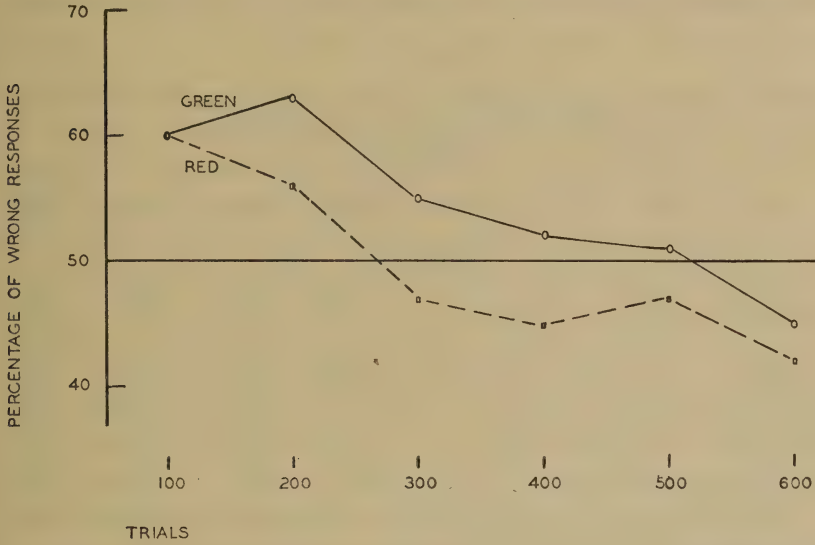
Fig. 4. The Gradual Decline (during 600 Training Trials) in the Percentage of Errors by Subject Dick during Practice with a Delay of 4 Seconds

response was restricted entirely to this side. Learning finally appeared in spite of the tendency to respond positionally.

When training was begun to the red cue, with an 8-second delay, reversion to the positional response was very rapid. After the second session, Don seldom pressed the left button, and at the end of 400 trials, training with neutral cues was introduced which "forced" use of the left compartment. The 45 trials given for this purpose proved only temporarily effective. Emotional tension continued to increase. The training limit of 600

trials was reached without any evidence of color discrimination. When delay of reward was eliminated from the training conditions, four sessions were given before improved performance appeared. On the fifth session, which completed 100 trials with immediate reward, Don suddenly (after three failures on the first three trials when the red cue was on the left) began to choose correctly. A score of 85 per cent resulted for this session.

Learning to the criterion might have been expected on the next session, but illness of the experimenter forced postponement

TABLE 4

Number of trials, errors, and position responses for color discrimination habits under varying conditions of reward-delay

Subject Don

HABIT	DELAY	NUMBER TRIALS	ERRORS	RIGHT CHOICES	LEFT CHOICES
	seconds				
1. Green.....................	4	420	176	356	64
2a. Red.....................	8	400†	209	387	13
		*			
Red.....................	8	200†	103	177	23
2b. Red.....................	0	210	78	175	35
3a. Green.....................	2	380†	208	351	29
3b. Green.....................	0	260	135	76	184
4. Red.....................	0	380†	211	249	131

* Forty-five trials with neutral stimuli were interpolated at this point to restore response to the left compartment.
† Failure.

of that session until 10 days later. Still with immediate reward, a score of 65 per cent was made on the session which marked resumption of work, the red choice giving way entirely to position preference during the second half of the session. The animal whimpered continuously after the seventh trial. During the afternoon session of the same day, Don made two correct choices to the left on trials 3 and 4, began whimpering, however, on trial 6, and then showed an entirely new type of response: On trial 10, following two errors, he brushed the orange from the right food-well and let it fall to the floor without eating it!

Though continuing to work through the remaining 10 trials, he repeated this performance on every rewarded trial. Whimpering accompanied the entire procedure. Refusal of food occurred again on the two sessions following. The value of further work clearly depended upon the reëstablishment of emotional and motivational adjustment to the experimental situation. As during part of the preliminary adaptation period, a second experimenter was introduced to remain with the subject in the response-chamber. Scores of 80 and 100 per cent were made on the morning and afternoon sessions, respectively, following this change.

Attempts to proceed with the establishment of a green habit at a 2-second reward-delay interval met with little success. The response to position increased its tenacity, and training to counteract the preference for the right side resulted only in its complete reversal. Subsequently the subject would respond always to the left on one session and entirely to the right on the next. Although the second experimenter continued to remain with the subject, sitting passively at the exit door opposite the apparatus, much of the emotional disturbance reappeared. A return to the immediate reward condition eventually brought learning of the green habit, but this success failed to effect any marked improvement in rapport. Work toward another no-delay reversal-habit was attempted. Restless movements by the subject increased. Occasionally the subject refused the orange for a period of several trials. If refusal occurred shortly before the end of a session, the subject quickly gathered up the pieces which had been dropped and stuffed them all into his mouth, immediately as the hum of the motor ceased, marking the termination of the work period. Extreme tension during the session seemed relieved as soon as the subject was picked up. Other characteristics of Don's behavior, such as, refusal to respond for periods as long as several minutes, and sudden bursts of screaming, gave his behavior during each session a strong resemblance to what has been described in the literature as "experimental neurosis." The intense emotional reactions of the subject made further testing in learning with delayed reward impracticable.

Summary. The subjects of the control experiment learned discrimination habits with immediate reward in much the same manner as similar visual discrimination habits have been learned by many vertebrates. Consistent response developed only after a relatively prolonged training period (60 to 180 trials). The temporal separation of the stimuli and the reward by 1 second or 2 seconds resulted in pronounced increases in the periods of training required. With delays of 4 and 8 seconds learning was not completed within an arbitrary limit of 600 trials. The only change in procedure from the immediate to the delayed reward conditions involved the disappearance of the color stimuli prior to the delivery or non-delivery of reward at the end of a constant response period.

B. Experimental subjects

The object of the experiment next to be reported was to determine the possible rôle of controlled previous experience in the ability of chimpanzees to learn discrimination habits. This experiment differed from the preceding with respect to the special training that was provided the chimpanzee subjects prior to tests of the relative effectiveness of immediate and delayed reward. The inclusion of Dick as a subject in both experiments provided a control for the possible artifact of individual differences in learning ability. There were available several methods whereby the training of distinguishing reactions to the color stimuli might have been undertaken. The question of their relative merits was a matter of conjecture. Means for establishing differential manual habits by the use of an upper vs. lower lever were provided in the construction of the apparatus, as were also devices for delivering different food rewards at two different locations. These methods were not made use of in work to be reported here. A third procedure was employed in accordance with an opportunity provided by a concomitant investigation being conducted with several primate subjects.

Special training procedure. An investigation of chimpanzee color vision (Grether, 1940) was in progress in the Laboratories during the course of the present experiment. In the apparatus

employed, spectral colors were provided by two monochromators. These colors were viewed by the subjects through two small plate glass windows. By pushing against either of these windows the animals gained access to food-reward pockets. Two kinds of tests of color vision were made. In the first, hue discrimination was measured at three spectral points. Discrimination was always shown by response to the stimulus of longer wavelength, which at two of the three points was the more red of the two colors. At the third spectral point the positive color was the more green of two blue-greens. The second type of test involved discrimination between white and various mixtures of complementary red and blue-green. In this study of complementary color mixtures the positive stimulus was always the one with the greater red component. For the selection of the more red of two cues, or in the one region the more green, Hal received small slices of banana; the other subjects were rewarded with raisins. When shifts were made to different test-colors, the transition was conducted in such a way that the discrimination habit was not disturbed. (Exceptions to the continuance of the response by Beta will be noted in presenting the results.) The three subjects, Hal, Tom, and Beta, and later Dick, also, mastered the discrimination response required in the study of spectral limens, and continued its use for a month or more prior to, and for several weeks during, the sequence of tests in delayed reward to be described. The chronological sequences of the two procedures, and the level of performance on the color vision test-habit, are presented for purposes of comparison in table 5.

The special preliminary training in color discrimination was carried out not only by another experimenter on another apparatus, using different foods for reward, but the location of the work was in a section of the building widely removed from that in which the delayed reward apparatus was situated. These provisions, coupled with the continued use and over-learning of the discriminative response, were probably important in the surrogate-function later manifested by the habit, or a derivative of the habit, in tests of learning with delayed reward.

Preliminary adaptation to delayed reward apparatus. Hal and

TABLE 5
Showing the chronological relations between the Grether color vision and the discrimination learning experiments

Approximate verbal equivalents of wave length designations:

500 mμ = blue-green
520–560 = green
589 = sodium yellow
600–640 = red

"Training": Performance roughly between chance (50 per cent) and 90 per cent
"Mastery": Performance 90 to 100 per cent in the direction of the "positive" color

DISCRIMINATION LEARNING DATES		COLOR VISION EXPERIMENT			
		Dates	Positive color	Negative color	Stage of habit
A. Subject Beta					
			mμ	mμ	
		7/23– 7/28	589	500–588	Training
		7/28– 8/8	589	500–588	Mastery
		8/22– 9/1	640	580–632	Mastery
9/14	Preference test				
9/14– 9/21	Three habits learned without reward-delay	9/20–10/4	589–506	500	Mastery
9/24– 9/29	Red habit, delay: 8 seconds				
9/30–10/3	Green habit, delay: 1 second				
10/ 4–10/17	Red habit, delay: 4 seconds	10/13 a.m.	610	White	56%
		10/13 p.m.	610	White	68%
		10/14 a.m.	610	White	100%
		10/14–10/18	610 + 495	White	Mastery
10/18–11/2	Green habit, delay: 2 seconds	10/19 a.m.	White	495	48%
		10/19 p.m.	White	495	96%
		10/24–10/26	White	495 + 610†	Mastery
B. Subject Tom					
		8/23– 8/29	589	500–588	Training
		8/29– 9/2	589	500–588	Mastery
9/16	Preference test	9/14– 9/27	640	589–632	Mastery
9/16– 9/24	Three habits learned without reward-delay				
9/24– 9/28	Red habit, delay: 2 seconds				
9/28–10/10	Eight habits at all delays	9/28–10/10	589–506	500	Mastery
10/10–10/17	Seven habits at all delays	10/13–10/19	610 + 495‡	White	Mastery

26

TABLE 5—*Concluded*

DISCRIMINATION LEARNING DATES		COLOR VISION EXPERIMENT		
		Dates	Positive color	Negative color	Stage of habit

C. Subject Dick

DISCRIMINATION LEARNING DATES		Dates	Positive color	Negative color	Stage of habit
			$m\mu$	$m\mu$	
		3/13– 3/14	589	500	Training
		3/14– 4/4	589	535–588	Mastery
		4/ 4– 4/6	589–560	500	Training
		4/ 6– 4/21	560–505	500	Mastery
		4/22	640	589	Training
4/25	Preference test	4/25– 5/9	640	600–632	Mastery
4/25– 4/30	Three habits learned without reward-delay				
5/ 1– 5/5	Five habits at delays through 8 seconds				
5/ 6– 5/15	One habit with 4 second delay				
5/15– 5/31	Four habits at 1, 2, and 4 second delays	5/31	615	640	All but 6 of 25 responses to 640, though unrewarded*
5/31– 6/6	Six habits at delays through 8 seconds				

D. Subject Hal

DISCRIMINATION LEARNING DATES		Dates	Positive color	Negative color	Stage of habit
		7/16– 7/23	589	500–588	Training
		7/23– 8/25	589	500–588	Mastery
9/17	Preference test	8/26– 9/20	640	580–632	Mastery
9/30–10/13	Three habits learned without reward-delay	9/21–10/5	589–506	500	Mastery
10/14–10/18	Green and red habits, 1 and 2 second delays	10/13–10/19	610 + 495‡	White	Mastery
10/19–10/29	Fourteen habits at all delays	10/24–10/26	White	495 + 610†	Mastery

Comparisons from this point on are shown in figure 7, p. 36, beginning with the reversal training between habits 16 and 17.

* Nine of the last 10 trials were to the red (640).

† Bluish.

‡ Reddish.

Beta were each given practice in the use of the response-button on the preliminary training apparatus, or food vender. Neither had learned to hold the hand steadily against the button when they were shifted to the delayed reward apparatus. Beta continued for some days to pound on the button-blocks, and in this way secured a jerky progress of the stimulus-carrier. The action of maintaining pressure gradually improved, however, until both subjects produced continuous excursions. Training of the lever-pulling component, and finally the combined response, progressed and was completed in much the same manner as described for Don in the control experiment. Hal required five more sessions for combining the two response components than had Don. Beta and Don each worked seven sessions to master the use of the lever in conjunction with the buttons. Beta acquired the habit of using the right hand on the lever and the left hand on either button. Hal developed just the reverse manual coördination.

Tom, who did not arrive from the Florida Laboratories until July 29, 1938, was started immediately on adaptation to the regular apparatus. He learned to push the buttons during the second session. After an additional session of practice, he was required to add the lever component to the response, and given help with it. Six sessions distributed over a period of 15 days served to establish a steady bi-manual response. Tom always used the right hand at the right window and the left hand for choice of the left window, in the same manner as Don. Dick continued, as during control tests, to use the left hand for pulling the burlap attachment on the lever, regardless of which button he was pressing.

Color preference tests. In order to discover to what extent the habits developed on the spectral color apparatus were likely to transfer to the experimental situation of the present study, the subjects were given tests of color preference prior to the beginning of training on the first immediate reward-habit. Upon introduction of the red and green colors in place of the gray stimuli used during preliminary adaptation, one session was devoted to the determination of possible preferences. All excursions were

followed by reward regardless of the color chosen. At the time of these tests each subject was responding to a spectral color of 640 mμ (red), as opposed to one of shorter wave length, on the Grether apparatus (table 5).

On the delayed reward apparatus Tom responded 100 per cent (20 trials) to the red. Dick chose red on 95 per cent of the trials, and Beta on 85 per cent, her three green choices all occurring on trials when green appeared at the left window. Hal indicated no transfer, selecting red on 11 of the 20 trials. In accordance

TABLE 6

Showing trials, errors, and position preferences (if any) for three color discrimination habits under the immediate reward condition

HABIT	NUM-BER TRIALS	ERRORS	R CHOICES	L CHOICES	HABIT	NUM-BER TRIALS	ERRORS	R CHOICES	L CHOICES
		Beta					Tom		
Green........	80	36	30	50	Green....	80	13	44	36
Red..........	100	47	43	57	Red......	60	14	33	27
Green........	60	25	27	33	Green....	40	5	21	19
Average....	80	36	33	47		60	11	33	27
		Dick					Hal		
Green........	80	12	42	38	Red......	60	17	25	35
Red..........	40	10	18	22	Green....	137	65	105	32
Green........	60	23	27	33	Red......	180	69	113	67
Average....	60	15	29	31		126	50	81	45

with these preferences, Tom, Beta, and Dick were trained first to select the green cue, whereas Hal duplicated the initial habit of the control subjects by learning to take the red.

Discrimination learning with immediate reward. The learning of the first three habits exhibited no consistent deviation from the results obtained with the control subjects. The numbers of trials required by subjects in the two groups overlap, as comparison of tables 2 and 6 shows (see also fig. 8). The average for the control group is 110 trials, and for the trained group, 81.5 trials. The outstanding individual performance was that by Tom on the

third habit.   For this habit, on the first reversal-training session,
errors (4 in number) occurred only among the first 6 trials, and
on the second session the one additional error occurred on the
first trial.
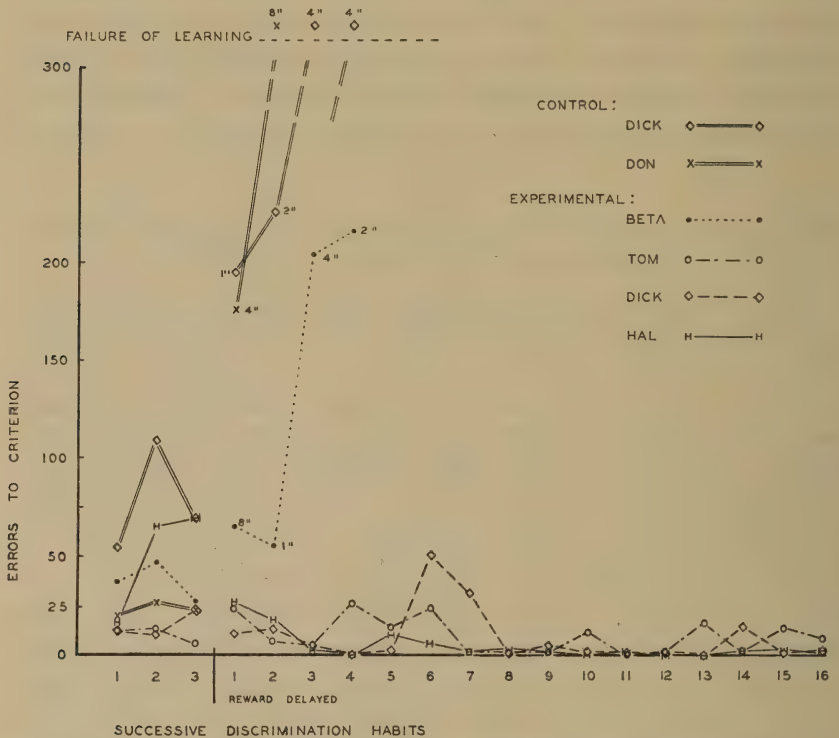
Fig. 5. The Number of Errors made in Learning Successive Reversals of
                    Red-Green Discrimination Habits
Scores of the control subjects are connected by double lines.   The first three
habits for each subject were established with immediate reward.   Delay inter-
vals not given adjacent to points on the graph are listed on page 31.

Discrimination learning with delayed reward.   With the in-
troduction of delayed reward the general comparability of the
results of control and experimental groups disappeared.   For
Tom, Dick, and Hal the separation of cue and incentive produced
no increase in the difficulty of the learning problem.   Indeed,
for Hal the score for the first habit-reversal with temporal

separation indicates pronounced improvement over the two reversals learned under non-delay conditions. The results for the experimental subjects are shown graphically in relation to the data from the control group in figures 5 and 8. Beginning with the fourth habit each point in figure 5 represents error scores for criterion learning of habits under conditions in which reward was delayed 1, 2, 4, or 8 seconds. The order of habits with each of these intervals varied from subject to subject. For Beta and the control subjects the intervals are marked at each point on the graph. The intervals of delay for Tom, whose first habit was to red, were 2, 4, 1, 8, 4, 2, 8, 1, 4, 8, 2, 1, 8, 4, 1, 2 seconds. For Dick, whose first habit with delayed reward was also to red, the order was 4, 8, 2, 1, 8, 4, 1, 2, 4, 1, 2, 8, 1, 4, 8, 2. Hal was started on delayed reward with green positive, and delays were in the order: 1, 2, 8, 4, 2, 1, 4, 8, 2, 4, 1, 8, 4, 2, 8, 1 seconds.

The averages of errors and trials required for the learning of reversals with each delay are given in table 7. Tom, Dick, and Hal were each tested on 16 delayed reward habit-reversals, 4 at each interval. The individual averages in the table are based on two habits to each of the colors. The results of tests with subject Beta are included in the table although they represent a special case which will be discussed separately. Examination of the averages shows that there was no consistent relationship between the time required for learning and the length of the delay imposed.

The relative difficulty of habits with each of the color cues is indicated by the averages shown in table 8. Although the data agree that for all subjects the red habits were slightly more readily learned than the green, the differences are not reliable. It is possible that the somewhat higher brightness value of the red cue was responsible for a difference here, as well as for the similar one reported for subject Dick in the control tests (fig. 4). The present results might also be interpreted as a manifestation of transfer of the habit utilized in the tests of hue discrimination —that of response to the longer wave length.

Performance of individual subjects. As a subject whose performance on the delayed reward tests lies midway between those

of the control subjects and those of the rapid learners in the experimental group, Beta presents a case of peculiar interest. Although her learning was slow, the direct relationship between rate of learning and length of delay shown by the control subjects is lacking. The discrepancy between the great difficulty of the

TABLE 7

The averages of errors and trials required for the learning of discrimination habits with varying intervals of delay between cue disappearance and reward or non-reward

	ERRORS				TRIALS			
	Delays							
	1 sec.	2 sec.	4 sec.	8 sec.	1 sec.	2 sec.	4 sec.	8 sec.
Tom (N = 4)............	5.5	14.5	6.2	14.5	35	45	35	55
Hal (N = 4)............	9.0	7.5	0.2	1.8	40	40	20	30
Dick (N = 4)............	8.5	2.5	20.0	4.2	45	25	65	25
Total average..........	7.7	8.2	8.8	6.8	40.0	36.7	40.0	36.7
Beta (N = 1)............	57	217	205	66	120	480	440	140

TABLE 8

The averages of errors and trials required for learning to each color during training with delayed reward. Delays were 1, 2, 4, and 8 seconds

	ERRORS		TRIALS	
	Green	Red	Green	Red
Tom (N = 8)...............	10.8	9.6	45	40
Hal (N = 8)...............	5.5	3.8	35	30
Dick (N = 8)...............	10.6	7.0	40	40
Total average............	9.0	6.8	40	36.7
Beta (N = 2)...............	137.0	135.5	300	290

4-second and 2-second delays as compared with the initial 8-second delay receives some explanation when the chronological sequence of Beta's performance in these tests is examined in relation to her performance on the Grether apparatus (fig. 6).

Beta's performance in the tests of color vision showed mastery (scores of 90 per cent or better) of the discrimination habit dur-

ing the entire period, beginning 6 weeks prior to any discrimination learning in the present work, through completion of the second delayed reward learning habit (table 5, A). That is, all three no-delay and the 8-second and 1-second delay-habits were learned during the time that Beta was successfully selecting the more red of two colors, or the more green of two blue-greens,
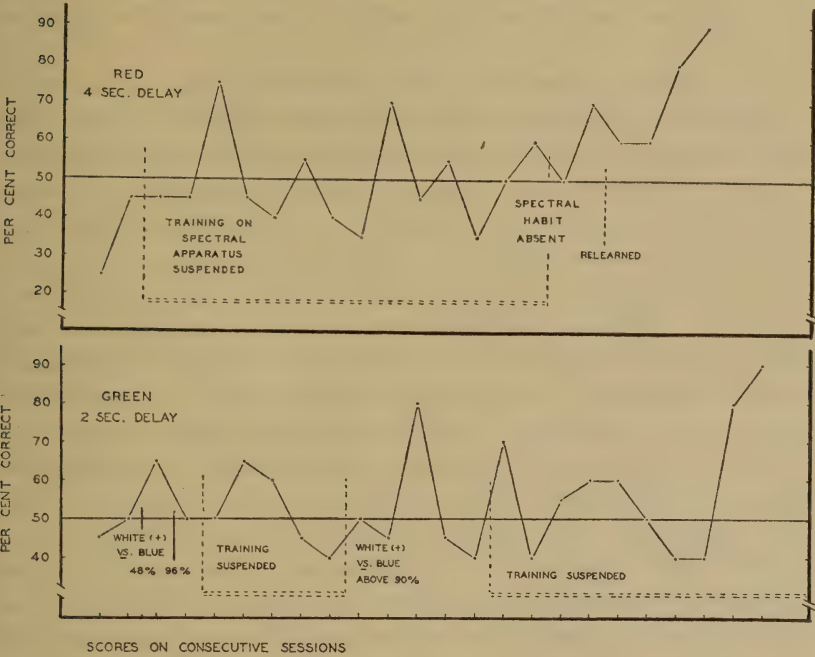
Fig. 6. The Learning Curves for the 3rd and 4th Delayed Reward-Habits of Subject Beta as Temporally Related to Performance in the Special Training (Spectral Color Vision) Experiment

when in the Grether situation. During the first two reversals with delayed reward, the positive cue was being reduced from a wave length of 589 mμ toward a comparison-negative cue of 500 mμ. Spectral hue discrimination tests were interrupted for a 10-day period following the second session of training with a delay of reward of 4 seconds. This period of interruption is indicated in figure 6 by the double broken line below the per-

formance curve for delayed reward learning. The graph shows how the response in the training with delayed reward fluctuated about the 50 per cent level over this entire period. When color vision tests were resumed, Beta had lost the red-choosing habit in the Grether apparatus. With subjects Tom and Hal this breakdown on the shift to color mixtures did not occur (table 5, B and D). Following Beta's re-training on the Grether apparatus, four sessions of practice with delayed reward sufficed to establish the reversal to the criterion level.

During the final green habit (2-second delay test), a change in the spectral hue discrimination experiment was instituted which again may have been responsible for the extensive training period required for learning with delayed reward. The limen investigation in progress when training at the 2-second delay began was completed coincidentally with the second training session. A shift from reddish (+) vs. white (−) to white (+) vs. blue (−) was made. Whereas subjects Hal and Tom transferred their choice-reaction immediately to the white (a red plus blue-green mixture) when this was paired with blue, Beta responded to white 48 per cent of the time on the initial session under this condition. After another session, during which she learned the response, work with color mixtures was interrupted for five days. Scores on learning with delayed reward remained at a chance level. Much of Beta's performance during this period was simple positional alternation. There ensued three days of work with color mixtures which indicated mastery of the white vs. blue habit.[5] Then work with spectral colors ceased. By this time Beta had received 280 trials of training on the green, 2-second delay habit. Two hundred additional trials were required before the habit was learned. The total score was thus quite comparable to that with the same length of delay made by Dick as a control subject.

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[5] Such mastery was very likely incomparable to similar performance by the other trained subjects. Since the latter transferred immediately, response-equivalence of white and red cues (when appropriately paired with other colors) was demonstrated. For Beta the white vs. blue habit may have furnished no symbolic reactions for the red vs. green problem.

The other three subjects, in contrast to Beta and the original control animals, showed remarkable facility for learning color discrimination habits with delayed reward (fig. 5). Tom, Dick, and Hal learned many habit-reversals within a single experimental session. Hal learned 10 of the 16 reversals with one or no errors, which represents the single-trial minimum of trial and error problem solution. Dick achieved this minimum on 6 reversals, while with subject Tom, 4 of the 16 habits were learned with one error or none.

Reversal of special training habit. Hal was continued on the delayed reward discrimination learning procedure with the introduction of various modifications in the training methods in order to investigate further the relation between the training derived from the Grether experiment and the present results. It was first proposed to determine the effect of a reversal of the habit on the spectral color apparatus upon the ability of the subject to reverse delayed reward habits rapidly. The large scale graph in figure 7 shows the results of Hal's first 16 reversals in relation to additional reversals trained following certain alterations in the concomitant spectral color-habit. The reversal of the habit of choosing the "more red" of two colors on the Grether apparatus was started by rewarding response to green on 50 trials. The technique used in the color vision study permitted correction of response whenever the subject failed to find food on the side first chosen. As can be seen from the figure (habits 17, 18, 19, for which delays were 2, 4, and 1 sec.), no immediate effect was apparent in the scores for delayed reward. After three sessions without the interspersion of any work on the spectral color apparatus, an additional session of 20 trials was given to insure the production of the opposite color-habit. Only 2 errors occurred during this session. Reversals with 8-second and 4-second delays followed (habits 20, 21), again with only 2 errors and 1 error, respectively. Interspersed between delayed reward reversals, there followed two reversals on the spectral hue discrimination apparatus, which were made by Hal with no errors! The explanation for the absence of initial errors lies probably in the fact that the subject chose the preferred right

hand position at the start of each session, which happened in both instances to contain the "correct" color stimulus. One-trial learning was apparently within the capacity of this subject in either of the color-discrimination situations.

Work by Hal in the spectral hue discrimination experiment was stopped entirely at this point. On the next session with delayed reward the subject persisted in choosing red, though unrewarded,
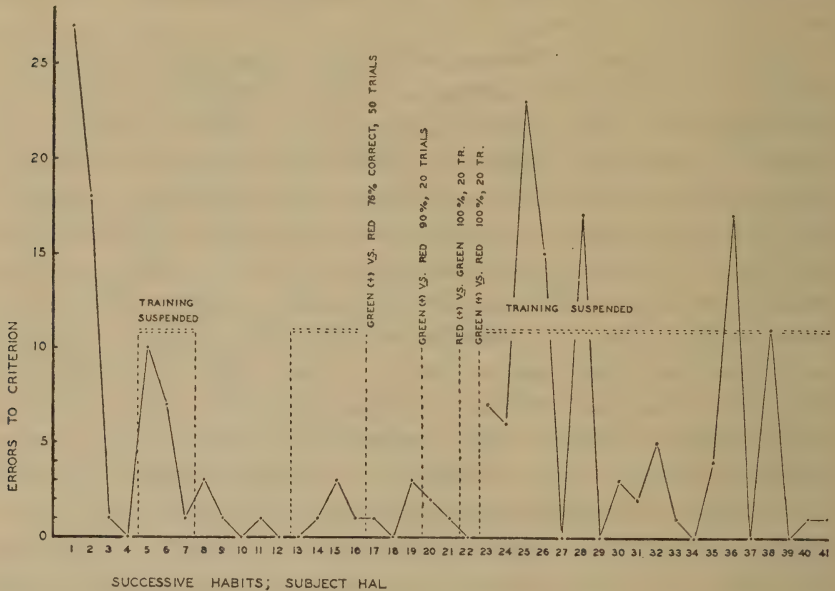
FIG. 7. THE EFFECT OF REVERSING THE GRETHER SPECIAL TRAINING HABIT
The solid line indicates error-scores made in learning successive habit-rever-sals with delayed reward. The dotted lines and the results summarized in print refer to work in the special training situation.

for 8 trials, and was beginning to whimper before he switched suddenly and completely to the rewarded green-response. This and the succeeding session involved an irregularity in procedure because it was originally intended to begin a reduction at this point in the length of each color-habit until eventually delayed alternation to color would be reached. The positive cues were reversed twice without permitting learning to the 90 per cent criterion. However, all 10 trials in the second half of each

session were correct, and this score (10 successive correct) would in itself be a highly reliable criterion of learning.

A total of 19 habits followed suspension of the special training. The mean number of errors per reversal was 6.0, as compared with a mean number of 1.8 for the 20 reversals (habits 3 to 22, inclusive) preceding the cessation of practice on the Grether apparatus. The t-value of this difference is 2.5, which represents a p (probability) in this case of 0.02 that the samples were drawn from the same population (Fisher, 1932, pp. 114 ff.).

The great number of factors which could have produced the falling off of performance in the degree represented by these figures renders their meaning uncertain. That the omission of practice on the special training apparatus did not abolish benefits of the training is clear, since speedy learning, and learning at all delay intervals continued. The surrogate-reactions to the colored stimuli were apparently capable of being maintained independently of their continued use in the situation in which they originally developed. What the outcome would have been if the Grether-trained habit had been reversed or stamped out earlier in the sequence of testing with delayed reward can only be surmised.

A rest period of eight weeks was instituted at this point. The subject resumed work with an uninterrupted habit in spectral limen determinations, but remained entirely away from the delayed reward situation. At the end of this time, tests of learning with delays of 1, 2, 4, and 8 seconds resulted in an average error score of 2.0. The first two reversals following the rest period were learned with 0 and 1 error (first trial), respectively. Eight weeks without specific practice in the reversing of color habits had produced no adverse effects on learning ability. This result contradicts the notion that the rapid learning rates exhibited by the experimental subjects can be accounted for on the basis of a temporary sharpening of ability due simply to intensive and continuous practice in reversing the discrimination habits.

Discrimination-reversals with longer delays. In order to make possible tests with longer delay intervals, a sprocket and chain

reduction device was installed in the apparatus. This permitted increasing the time for the excursion of a stimulus-carrier from 10 seconds to as long as 40 seconds.

It was not surprising, in view of the long habituation to the 10-second excursion, that Hal showed signs of frustration when slower speeds were used. As can be seen in table 9, no success was ever achieved at the slowest rate of movement. Six short-ened sessions, averaging 10 trials each, devoted to adapting the subject to this rate early in the sequence, demonstrated that emotional disturbances were preventing learning even when there was no delay of reward (between *stimulus-disappearance* and food). The time required for each excursion was reduced to 27 seconds. Learning to the usual criterion with two errors or less for each habit occurred at this rate with delays of reward up to 20 seconds. However, the motivation of the subject con-tinued to show gradual impairment, as indicated by increasing periods of play behavior prior to response, whimpering during the progress of the stimulus-carriers, and interruptions during excursions by clicking of the response-buttons. Delay of re-ward actually averaged several seconds longer than the figures indicate because of the discontinuity of the carrier motion pro-duced by the failure on the part of the subject to maintain steady pressure against the button.

In view of these difficulties, which seemed a function of mo-tivational factors independent of any difficulties intrinsic to the association required, it cannot be said that the 20-second inter-val represents a limit beyond which the association between the color and the appropriate response could not have been effected. No indication of the maximum time span is afforded by these results.

The data do render extremely unlikely an explanation of the remote association in terms of visuo-sensory reverberations or after-image effects. An after-image explanation is further ren-dered implausible by the results in general. The characteristics of visual after-images to color would lead to the expectation that at certain delay intervals negative rather than positive associa-tions to the cue should have occurred. At no time were such

tendencies manifested. To several human observers, who were tested under the conditions of the experimental work, the only after-image phenomenon that appeared was a weak complementary (green) sensation of very brief duration following the disappearance of the red cue. This was observed only when the focus of vision was maintained on the illuminated surface within

TABLE 9

Showing results of delayed reward learning by Hal with longer delay intervals

COLOR HABIT	DELAY OF REWARD	EXCURSION TIME	SCORES, IN PER CENT TRIALS CORRECT PER 20 TRIALS
	seconds	*seconds*	
1. Red.....................	4	10	100
2. Green...................	4	10	80, 95
3. Red.....................	8	27	60, 95
4a. Green.................	16	40	50 (2 sessions)
4b.	4	40	45 (2 sessions)
4c.	0	40	40 (2 sessions)
5. Green...................	4	27	50, 90
6. Red.....................	4	27	60, 100
7. Green...................	8	27	95
8. Red.....................	8	27	90
9. Green...................	16	27	95
10. Red.....................	16	27	95
11a. Green.................	24	27	45
11b.	20	27	90
12. Red.....................	20	27	90
			PER CENT TRIALS CORRECT PER 10 TRIALS
13. Green...................	24	30	50, 40, 70, 100
14. Red.....................	24	30	70, 50, 100
15a. Green.................	32	40	60, 50, 50
15b.	24	30	70, 40

the food chamber. Furthermore, the appearance of this after-image differed markedly from the green stimulus employed. It was of much lower saturation; its area was indefinite; and the background of white light surrounding it served to differentiate it from the stimulus color in a pronounced way.

There is a final argument against an explanation of successful discrimination learning with delayed reward in terms of simul-

taneous associations based on after-images: On such a basis the
control subjects should have learned the associations as readily
as did the animals of the experimental group.

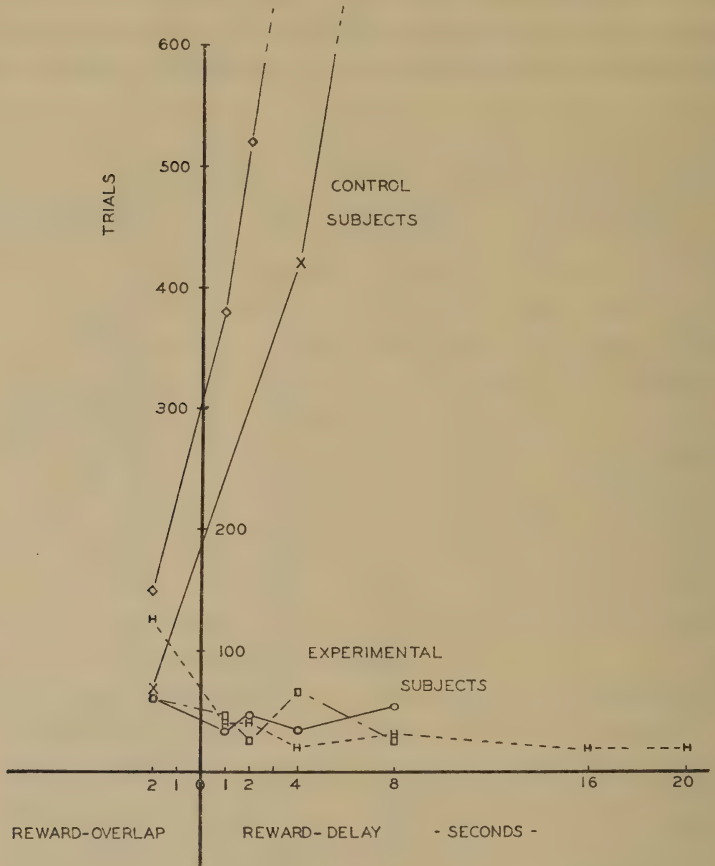Fig. 8. The Comparison Between the Learning Times of the Control and
the Specially Trained "Experimental" Subjects
Habits with "reward-overlap" preceded those learned with delayed reward by
all subjects.

C. Résumé

Control chimpanzee subjects with no previous experience in
visual discrimination experiments learned color discrimination
habits normally when reward or non-reward occurred in the pres-

ence of the colors to be discriminated.   Under conditions of delayed reward (1 and 2 seconds) learning time was greatly prolonged, and with separations of 4 and 8 seconds the animals failed to learn in 600 training trials.

Subjects previously trained to respond to colors on a separate apparatus in a different room with different food as reward, and who continued to practice this discriminative response during the course of a portion of the delayed reward tests, were able to learn delayed reward problems.   The length of the delay (0, 1, 2, 4, 8, 16, or 20 seconds) had no effect on the rate of learning for these specially trained subjects.   Learning frequently occurred with the first trial of a color habit-reversal; i.e., so that no errors occurred on the remaining trials of the session.   One-trial learning also appeared in the reversals of habits learned on the special training apparatus.

The control subjects, Dick and Don, required 2340 trials and 1870 trials to learn 4 habits and 3 habits, respectively, when separation of the stimuli and the incentive on each trial was no more than 4 seconds.   The experimental subjects, Tom and Dick, learned 16 habits in 680 and 640 trials, respectively, with delays of 1, 2, 4, and 8 seconds.   Hal learned 41 such habits in 1230 trials.   Beta responded less consistently to the special training given the experimental group.   Her learning scores on delayed reward habits represented a stage intermediate between those of the two main groupings.

The comparison between the control and the experimental subjects (with Beta's results omitted) is shown graphically in figure 8, where learning time, plotted in terms of trials, is presented as a function of the temporal relation between the stimuli to be discriminated and the reward vs. non-reward.

IV. DISCUSSION

A. Representative reactions

The results of this experimental study support the following proposition:

The learning of a problem having a remote after-effect can take place only when the relevant stimuli evoke a discriminatory reaction

at the time of their occurrence.   If neither an overt nor an implicit reaction occurs at the time of stimulation, the cue is lost to the organism, and delayed differential consequences (reward or punishment) are of no avail in the modification of behavior.

The precise manner in which established associative reactions may function in a signifying rôle to mediate learning with delayed reward was not implied in the original assumptions, nor was it demonstrated by experimental observations.   Certain properties of the mediating processes can, however, be inferred from the requirements of the delayed reward problem.   These properties have to do with the temporal course of the intermediate reactions and with the manner in which they may operate in the new association.

The delayed reward problem may be diagrammatically presented for purposes of analysis as shown in figure 9.   In this schematization "S_fR_f" designates the goal behavior.   Chimpanzees without special training were unable to associate the positive color, "S_+," with the appropriate choice-response under the conditions indicated in the first diagram.   It was necessary to provide for the establishment of a representational process by means of which the animal could "hold" the stimulus during the delay interval.   On the assumption that this may best be expressed in stimulus-reaction[6] terms, a second diagram is used to indicate the process by which such a representation may persist during delay with trained subjects.   The stimulus-reaction sequences added here constitute the representational reactions to the colors, or, in previous delayed reward problems, which have employed spatial cues, the sequences would apply to the symbolic counterparts of the locations to be discriminated.   Learning with delayed reward requires that these reactions persist during the delay period, in order that there be a differential result of color stimulation (or spatial cue) within the organism at the time of reward.   Reward does not work back upon activity that has been completed.   Only when activity remains differ-

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[6] The word "reaction" is used in the present discussion for the sake of distinguishing implicit or not directly measurable activity from overt "responses." In the diagrams "r" represents a reaction, and "R" a response.

ential until reward occurs[7] does reinforcement of such activity result.

Following the establishment of representative reactions to color, the experimental subjects of the present study frequently reversed their responses on the basis of a single trial. Sometimes
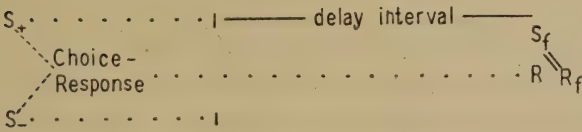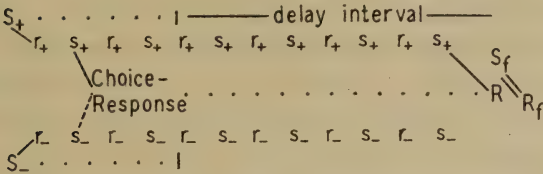
Fig. 9. A Diagram of the Stimulus, Reaction, and Response Relationships Assumed to be Operating in the Delayed Reward Situation before and after Special Training

Double lines indicate strongly over-learned associations developed early during the normal course of an animal's life. Single lines indicate associations learned during the experiment or in the special training of the "experimental" animals. Dashed lines indicate failure of association. The sequence of events in time is indicated from left to right. The "s₊—Choice-Response" bond, however, in the second diagram, must be considered absent at the left until the remainder of the sequence has occurred. (Further exposition is given in the text.)

this initial trial was a correct choice and sometimes an incorrect one. The manner in which an initial error could bring about

[7] Under certain conditions the differential activity might lapse during delay and be associatively reinstated at the time of reward. For example, symbolic behavior called forth by the visual stimulus in one location should be associatively reinstated when the organism returns to that location.

learning may be traced by reference to the diagram. In the event that the negative color was chosen, the reinforcing goal activity, "S_fR_f," failed to occur. The association or conditioning of the choice-button response in such cases did not become strengthened to any stimulus. On the contrary, the strength of the "$s_- \rightarrow R$ (choice-response)" tendency diminished.[8] On the following trial stimulation from the positive color and the resulting "s_+" thus aroused the stronger response-tendency.

While it is not essential to the theory to postulate the precise nature of the intermediate reactions that may have been involved, the character of the training conditions in the situation for spectral hue discrimination provides certain general indications. The one requisite is that reactions capable either of self-perpetuation or reinstatement shall have been conditioned differentially to the color cues. For example, Hal had learned to "expect" a slice of banana when he pushed on the more red of two colors. He furthermore developed a very definite eating routine which involved pressing the banana into the wire mesh of the cage and then sucking it off with his lips. The kinesthesis was probably quite specific and at the same time rather elaborate. Supposedly, a degree of this kinesthetically mediated "expectancy" (cf. Cowles and Nissen, 1937) transferred to the delayed reward situation. Here, however, it was not directly reinforced by the eating of banana. As a differential internalized reaction, on the other hand, it was rewarded by successful attainment of the goal behavior appropriate to the new situation. In other words, it became independent of the overt eating of banana, for banana was not "expected" in these experimental circumstances—at least, not after several days of differential training,[9] which presumably served to restrict the transfer to implicit anticipatory reactions. Implicit "pushing" on the red combined with banana-eating movements could be carried out in the new situation whether the subject operated the lever and R button, or the lever and L button. As differential

[8] For a quantitative study of extinction as the result of the non-reinforcement of a Thorndikian response, see Youtz (1938).

[9] I.E., during the first habits learned, with immediate reward.

tonus in specific sets of muscles, the anticipatory reactions previously acquired and independently maintained could thus function to guide adjustments to the shifting delayed reward problems.

Representational reactions for spatial cues do not require special training, a fact which probably gives them a distinct advantage over experimentally established reactions. This is indicated by the readiness with which animals adapt in spatial delayed response and in learning spatial habits with delayed reward. Reactions to position are necessarily learned early in the lives of higher organisms, and function continually thereafter. They are part of the organism's everyday reaction-repertory. A further advantage is probably derived from the close relationship between the symbolic reaction and the overt spatial discriminative response. Whereas the trained representative reactions to color in the present experiment possessed the arbitrary relationship to the stimulus of a *symbol*, a representative reaction to position is probably related to the positional cue as an *icon* (Morris, 1938, p. 24). That is to say, the positional reaction may be the reduced or internalized counterpart of the overt positional response.

An observation by Wolfe (1936) illustrates the nature of the habit which is assumed to have functioned as a representation of the visual stimulus in the present experiment. A chimpanzee trained to use white poker chips for obtaining grapes from a food-vender behaved in the following manner:

Just as a white token was extended towards her, she smacked her lips as if anticipating food. A grape was then extended toward her in the same way and the lip movements again occurred. Further observations were made of the anticipatory lip movements just after the subject had learned that brass tokens would not obtain food. The white tokens and the grapes would elicit the lip smacking but the brass tokens would not do so. (Pp. 15–16.)

Detailed analyses of the processes by which "anticipatory goal reactions" may mediate "purposive" behavior in animals have been presented by Hull (1930, 1931). It has been demonstrated

experimentally by Miller (1935) that responses conditioned to a feeding device in which distinctive movements were required transferred to earlier portions of the path leading to this goal. Animals shocked in a reward device different from that experienced at the end of the path did not show transfer. These results were to be expected on the assumption that reactions which produce self-stimulation at the feeding device also occur, because of previous conditioning, in the path to food, where they are termed (after Hull, 1931) "anticipatory goal reactions" or "pure-stimulus acts."

Verbal signifying behavior may frequently function in human adaptations to a non-social environment. Whereas gross motor adjustment is often hampered or prevented by the immediate conditions in which the individual finds himself, anticipatory adjustment in the form of vocal or sub-vocal speech is usually possible. Esper (1935) has termed the derivative use of language in the "constructive" manipulation of objects, "non-social speech." A linguistic response "may be continually repeated during a sequence of manual and locomotor acts (thus serving to guide and maintain these acts) without interference with the overt behavior" (Esper, p. 453).

The advantage which linguistic habits may provide is demonstrated in a striking manner in an experiment by Gellermann (1933). The example is particularly appropriate for the present discussion because it involves a discrimination problem. Chimpanzees and two-year-old children were subjects. Two small boxes provided the hiding-places for cookies that were used as reward. A triangle was always placed adjacent to that box, selected at random, which contained the cookie. Five-year-old chimpanzee subjects required over 800 trials to learn to open the designated box. The little boy, Jimmy, learned to choose the box containing the cookie on the 220th trial. For him solution was accompanied by verbalization: "Dis one," and by his tracing of the triangle with one finger. Nancy G. learned the problem without ever making an error. Tracing the outline of the two upper sides of the triangle with her right forefinger, she said, "That's a A," and then secured the cookie. This discriminative

response, based upon previous experience with a similar visual form, had apparently transformed the problem into a single-trial-learning task. The prompt utilization of a cue seems also to be correlated with linguistic responses in data secured by Miller (1934). He reports that color did not serve as the basis for delayed response in children younger than two to three years. Up to 24 months children responded on the basis of position. Although the color-naming ability of the children is not stated, they began to respond on the basis of color at the age range during which colors are first identified verbally.

B. Other concepts

Observation of one of the control subjects during an unsuccessful training session with delayed reward prompted the remark by a non-professional observer that "the chimpanzee did not seem to pay any attention to the colors." To have characterized the behavior of the trained subjects as highly attentive would have been equally appropriate. Spragg (1936) has invoked the concept of "attention" as one means of accounting for the failure of chimpanzees to learn a temporal maze problem. Krechevsky (1938, p. 132) has offered the suggestion that in discrimination learning "only when the animal begins to 'pay attention to' or 'react to' the important stimuli does reinforcement have any effect." To define 'paying attention to' as meaning 'to react to' conforms precisely with the explanatory concepts advanced above to account for the differences between learning before and after intermediate reactions had been developed. The basis of 'attentive' behavior may well lie in implicit reactions.

The performance of the experimental subjects is not unlike that often described as evidence for "insight" and reasoning. These terms, utilized to specify cases of the immediate or sudden elimination of incorrect responses at a choice point, imply in themselves only a difference in the mode of problem-solution. They do not designate the basis for the difference between trial and error as opposed to sudden learning. In the experiments of Maier (1929, 1932, 1938) and of Tolman and Honzik (1930,

1936) the cues on which response depended were such as are known to be efficacious for single-trial-learning; that is, they were spatial. The evidence for the difference between spatially constant cues and those without spatial relations in terms of their relative effectiveness in delayed response and in learning with delayed reward has been summarized in the introduction. As long as tests of insight employ situations, such as the spatial, to which the subject reacts immediately and specifically, the single-trial-modification should presumably be obtained. In the *Umweg* tests the correlated ability for learning with delayed reward must play its part. That is, a reaction at a choice-point must be retained or altered on the basis of the reward or non-reward experienced later in the path. The equivalence of, or transfer of habits to, identical segments of different routes must also be assumed. Maier (1939, p. 325) has, in fact, reported a "marked correlation . . . between reasoning and equivalence scores, suggesting that transfer is associated with the ability to reorganize past experience."

C. Neurophysiological implications

The persisting or recurrent stimulation necessary to provide a representation of the cue when reward occurs after a delay has been tentatively ascribed to a proprioceptor system. The nature of the associated responses and assumed reactions favors this interpretation. However, the degree of reduction from the original gross motor associative responses is not necessarily restricted to peripheral neuromuscular processes. The possible limit would appear from evidence of structure to be the reduction to impulses in recurrent collaterals within the architectonic layers of the cerebral cortex (Lorente de Nó, 1938). This possibility, however, is open to question for the reason that in higher nervous centers "long-lasting after-discharge hardly ever appears without a background of tonic activity, which obviously is due to a continuous stream of impulses arriving either from the periphery or from other centers" (Lorente de Nó, 1938a, p. 234). Present knowledge of central nervous function does not furnish a basis for eliminating either possibility.

The data of the control experiment have special implications with respect to neurophysiological function.   The learning with short delays can be interpreted as dependent upon sensory after-discharge following cessation of the external visual stimulation. The delay intervals (up to 4 sec.) still found to produce learning of the discrimination habit are well within the range of after-discharge effects measured in studies of brain potentials.   The duration of such effects varies considerably with the strength of the stimulus and with the point along optic pathways at which measurements are taken (Gerard, Marshall and Saul, 1936; Dubner and Gerard, 1939).   The periods of after-discharge reported vary from a fraction of a second to more than two minutes.   The range is somewhat shorter in the lateral geniculate radiations and occipital cortex than in the optic tract and hypothalamic region.   Data are not available, however, for non-narcotized animals (where the duration would presumably be less prolonged), and conclusions must therefore be restricted to the observation that the above interpretation of the outcome of tests of "remote" association is not contradicted by neurophysiological evidence.   The possibility exists that the learning of habits with delayed reward to stimuli lacking symbolic representations may offer a means for correlating temporal relations in action-currents with temporal relations in associative function.   The locus of the centers involved in the association would be open to demonstration by such a technique.

D. The "retroactive" effect of reward

The logical difficulty that appears when learning data must be interpreted in terms of a retroactive operation of the consequences of an act has been held responsible by McDougall (1933, p. 353) for a "general reluctance to accept Thorndike's law of effect."   This problem of the backward action of reward is given a specific answer in the present experiment.   The results of the control study demonstrate that, strictly speaking, there is no backward action.   The performance of the experimental group is indicative of the conclusion that in order for a reward to have an effect on preceding behavior, there must be a per-

sistence of activity that is a representation of that behavior, and such activity must continue until the rewarding event has taken place. This explanation eliminates the need for the concept of "retroaction" in the law of effect and frees it from any embarrassment attendant upon such a logical difficulty.

V. SUMMARY AND CONCLUSIONS

An apparatus for the study of the learning of visual discriminations made possible the variation of the temporal relation between the stimuli and the reward or non-reward. In order to isolate this single variable, equalization of the subject's activity in amount and direction and equalization of the degree of frustration of delay were provided for. Work with five chimpanzees yielded the following conclusions:

1. Control subjects confirmed the general finding in visual discrimination work with animals that when reward is immediate, consistent response to one of two stimuli requires differential reinforcement over a period of many trials. In the present tests with colors the range was 60 to 180 trials.

2. When reward is delayed more than a few seconds, visual discrimination learning is extremely difficult or impossible. In the present study control subjects failed with delays greater than 4 seconds. (Retarded learning with delays up to 4 seconds may perhaps be explained by assuming sensory after-discharge.) No instance of animal learning with delayed reward, which depended unequivocally upon non-spatial stimuli, has been discovered in the literature.

3. Subjects of the experimental group were given special preliminary training in an independent situation. The establishment of a reliable and persistent color discrimination habit made possible single-trial-learning of color discriminations on the delayed reward apparatus. Solutions containing one or no errors were achieved as frequently with longer as with shorter delays between the stimuli and reward or non-reward. This suggests that, if given the proper previous experience, animals can achieve sudden solutions characteristic of problem-solving by means of symbols. Spatial cues such as are instrumental in the normal

daily adaptations of animals are known to be especially efficacious for single-trial-learning.

4. Learning with delayed reward is directly related to the dependability of a pre-established discriminative response and to the degree to which the crucial stimuli exhibit equivalence. A chimpanzee in the experimental group of the present study whose pre-established habit required re-training during the course of its use, and whose performance showed less stimulus-equivalence, produced scores intermediate between those of the other experimental subjects and the control subjects.

5. Learning with delayed reward, and cases of failure of such, can best be explained by the assumption that such learning is dependent upon intraorganic s-r-s sequences which serve as representations of the critical stimuli until reward or non-reward occurs.

6. Spatial stimuli appear to be the only variety to which animals ordinarily perform symbolic reactions. Learning with delayed reward, delayed response, reasoning tests, and tests of "insight" or capacity for single-trial-learning are measures of representative function. Special training can effect an expansion of the area of activity in which an organism may exhibit symbolic behavior.

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A Study of Experimentally Induced Competitive Behavior in the White Rat

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A STUDY OF EXPERIMENTALLY INDUCED COMPETITIVE BEHAVIOR IN THE WHITE RAT

CHARLES NELSON WINSLOW

Brooklyn College, Brooklyn, N. Y.

A. PROBLEM AND METHOD

When a goal object is greatly desired by one individual, the presence of another individual who is seeking or who is judged to be seeking the same object frequently serves as a stimulus that will ostensibly intensify the efforts that the individual will make in order to reach the goal. When a goal object is too difficult to be obtained by one individual alone, the two or more individuals striving to obtain it may submerge their competitivness, and work together conjointly to obtain the goal through coöperation. The competitive effect from the presence of another individual is generally considered to be more primitive than the coöperative effect. In fact, the concept of struggle for existence in Darwin's theory of organic evolution would seem to make it a basic principle of all nature. The psychologist, however, would restrict the scope of his concept of competition to behavioral situations in which some specific goal is mutually desired by the striving individuals, or to the scope of the definition in Warren's Dictionary of Psychology, "the contention of two or more individuals for the same object or for superiority."

The question as to how far down in the evolutionary scale the competitive effect of one individual upon another can exist is a most interesting one, and one at present very inadequately answered. Coöperation undoubtedly is a higher level form of social response than competition. It is defined in Warren's "Dictionary" as "the working together of two or more units of a group in such manner as to produce jointly some effect." It seems to the writer that coöperation should be considered a

1

higher level form of response because it probably involves a process of reasoning through which the relationship between the strength or force of the other individuals in the group and the unattainability of the goal object when the one individual is striving to obtain it alone is perceived. Coöperation, like competition, has always been considered to be a broad biological principle. A biologist such as Allee (1), however, draws a distinction between "innate" coöperation and "voluntary" coöperation, considering the former to be a fundamental property of protoplasm. He also significantly points out that it is undoubtedly easier to observe competition in animal groups than to observe coöperation, since the latter may be present only in a massing together of individuals for their mutual benefit.

Most of the observers of animals working in groups of two or more have interpreted an increase in the amount of food taken by the individual in the group over the amount taken when eating alone to be the result of "social facilitation." This term, the writer considers, should not be used interchangeably with the term "competition" as some writers seem to have done. The distinction between an active competitive situation and a situation which elicits social facilitation should be based upon the criterion as to whether a premium is placed upon the speed of running or upon the strength of the individuals in the group, so that those which do not reach the goal object first are deprived of access to it, or can get it only by snatching it away from the winner. A situation which fulfills this description would be an active competitive one, but a situation in which all individuals have access to the goal object, usually food, without struggling and thwarting, and the amount of food that the individual eats is compared with the amount that it eats alone, is what the writer would call a social facilitation situation. A number of investigators apparently have assumed a distinction somewhat analagous to this, but have not directly expressed it. The feeding of hens under the conditions of a social facilitation situtation has been studied by Bayer (3), who found that the amount of food ingested was always increased by the presence of other hens, and that 60 per cent or more would be eaten by the already

satiated bird under the social influence of another hen brought in when hungry. Welty (16) observed that fish devoured more food in groups than when isolated. Harlow (6) has shown that in rats the individual is affected by the group in the same way. Group facilitation upon the number of times that thirsty rats would cross an electric grill to drink has been reported by Rasmussen (11). The feeding of monkeys was subject to group facilitation, Harlow and Yudin (7) found. The monkeys paid much more attention to each other than did the rats, however. Harlow and Yudin also observed that under such conditions definite attitudes of ascendance and submission arose in the monkeys.

The presence of other individuals does not always exert a facilitatory effect upon the performance of the organisms as Gates and Allee (5) showed in the cockroach. They found that isolated cockroaches made fewer errors and took less time in maze learning than paired cockroaches, and that paired cockroaches in turn were superior to a group of three. The pairing of parakeets in maze learning by Allee and Masure (2) also resulted in social interference, and the sex of the paired birds was shown to have no effect.

An experiment that undoubtedly bears upon the problem of social facilitation and competition is that of Waters (15) upon group and individual maze learning by the rat. The report of the experiment is so condensed, however, that the description of the results is limited to the statement that there was no significant difference between the rate of learning in the group and in the rate of learning in isolation. Unfortunately the experiment has not been reported more fully elsewhere, as far as can be ascertained, so that no adequate description of the conditions is available. It would be interesting to know, for example, whether each animal reached a separate goal, or whether there was only one goal which the fastest learner was permitted to reach.

The study of competitive behavior in the white rat reported by Lepley (8) is the most germane to the present experiment. The competitive apparatus consisted of a thirty foot straight runway

with a two compartment entrance box at one end and a two compartment goal box at the other. The measure of the effect of competition was the rat's speed of locomotion from the entrance to the goal box, which was entered by means of climbing or jumping over the fixed gate.

The 12 rats were run first in isolation until each had reached a speed of locomotion plateau. Thereupon they were run in pairs for 40 trials, each member of the pair receiving the reward. The crucial test consisted of 160 trials in which only the winning rat was allowed to enter the goal compartment to secure the food. Lepley found that the average running time of the rats was .08 seconds shorter in the paired running than in the last 10 trials of running in isolation, a difference that proved to be statistically reliable. Although the winners and losers were quickly segregated from each other, Lepley was somewhat doubtful that the difference in the speed of running was the result of direct competition, but expressed the view that the frustrations encountered by losing released some unidentified motive such as that of social facilitation or of escape.

Innate or unconscious coöperation as a primitive form of social adaptation has been experimentally studied by Allee and his students (1) in many invertebrate as well as vertebrate forms. The writer of the present paper, however, was interested in establishing an experimental situation in which "voluntary coöperation" would be elicited in the rat, if the animal was capable of it. Experimental studies of this form of coöperation have been limited to primates. The investigations of food sharing in chimpanzees by Nissen and Crawford (10), and of coöperative problem solving in chimpanzees by Crawford (4) offer the most tangible evidence. In the former experiment it was demonstrated that unsolicited as well as solicited sharing by friendly animals frequently occurred. In the latter experiment the chimpanzees were presented with a box-pulling task. Each chimpanzee first learned individually how to secure food by pulling a rope that was attached to a weighted box. When the box was pulled within reaching distance, the animal could take the food from the top. The weight of the box was then made too

heavy for one animal to pull.   Two ropes were attached which, if pulled by two chimpanzees simultaneously, would bring the food on top of the box within reaching distance of both.   All five chimpanzees coöperated to this extent, and furthermore, all evinced a second stage, that of watching the partner and responding to its pulling in one way or another.   Two of the animals reached a third stage of gestural solicitation of the partner to get him to pull.

Altruistic food sharing as well as competition has been demonstrated by Mowrer (9) in the white rat.   He found that with repetition competitive behavior tended to wane, and food-sharing appear in its place.

Two important questions which the investigator of competition in either humans or animals is usually interested in answering are: 1) What types of situations of pairing and grouping animals elicit competition; and 2) What is the effect of winning and of losing upon the quantitively measurable performance of the animals?   Two other questions which have been raised only occasionally by investigators of competition are: 1) What are the effects upon the personality or behavioral integration of those individuals of the competing group that constantly win or constantly lose; and 2) To what extent are the competitors responding to each other as individuals, and consequently to what extent do their performances vary from competition with one competitor to another?   The writer proposes to attempt to answer these four questions with reference to the white rat. Two experimental situations were selected for the study of competition, which are described respectively under the headings of Competition Experiment I and Competition Experiment II. A third experimental situation, Experiment III, was designed to elicit coöperative behavior, if the white rat is capable of it.

B. EXPERIMENT I.   COMPETITION

The experimental situation in many respects was comparable to that of Lepley (8) in that the rats were competing with each other in speed of running on a straight runway from the entrance compartment to the goal compartment where the winner found

food (fig. 1). There are several details of the apparatus that deserve some mention. The two-compartment entrance box was divided into two parts by a heavy acetate transparent partition, making it possible for the two competing rats to observe each other during the stage preparatory to running. It was believed that cues from the other animal might arouse the competitive urge before both rats were actually released into the runway. In order again to increase the cues from the other rat, the door leading from the runway to the goal compartment was made of transparent acetate, with the result that the losing rat upon reaching the closed goal-compartment door would be able to see the winner devouring the food.
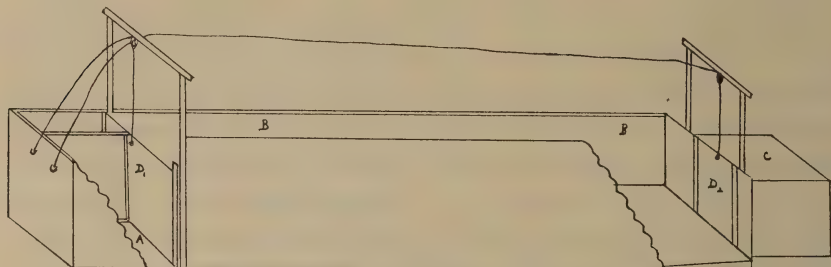
FIG. 1. COMPETITION APPARATUS IN EXPERIMENT I
A, two compartment entrance box with transparent door D_1 leading to runway B; C, goal-box entered from runway through a transparent door D_2.

The runway used in this experiment was considerably shorter than that used by Lepley. In view of the writer's desire to utilize the cues that one animal might give to another, it was deemed advisable to have a runway short enough to preclude the likelihood that the two competing rats would be separated from each other by a distance too great for the focusing power of the rat's eye.

The entire apparatus inside and out was painted a battleship grey. Both of the acetate doors were operated by the experimenter by means of cords and pulleys controlled from behind the entrance compartment.

The 18 rats used as subjects included 7 males and 11 females. A high level of motivation was induced by 24 hours of food

deprivation. As a preliminary, each rat was permitted to eat and explore for 2 minutes in the goal compartment before being put into the runway at all. The next day each was put in the
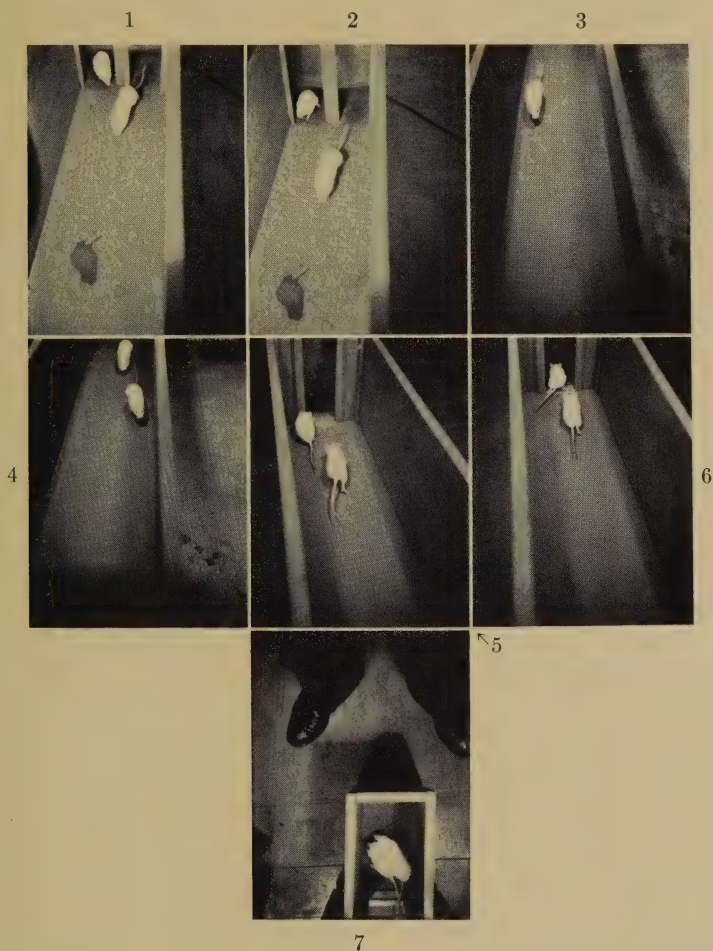
PERFORMANCE OF TWO RATS THAT ALMOST TIE IN REACHING THE GOAL-BOX

1. The two rats leaving the entrance compartment.
2. One of the rats gets off to a start before the other.
3. Now he is about one foot ahead of his opponent.
4. But other rat is beginning to run faster.
5. He is now catching up.
6. They are now entering the goal-box almost together.
7. In the goal-box together they fight for the single piece of food.

entrance compartment and allowed to run over the runway alone. This was continued at the rate of 3 trials per day until the animal immediately left the entrance box to go down the runway to obtain food in the goal-compartment, and had definitely reached a speed of locomotion plateau. When these criteria had been attained, the rats were considered ready for the competitive tests. In selecting competitors, the experimenter was interested in pairing animals that were closely matched in speed of running in order to induce a high degree of tension. But it sometimes proved so difficult to do this, that in the actual pairings a wide range in the individual speeds of running were represented. Each animal was tested in competition with both cage and non-cage mates. At a single experimental period each competing pair received three or four trials. The total number of trials given each pair was ten. Protocols were kept of the behavior of the winners and losers from trial to trial in addition to the running time of each.

The quantitative results of this experiment are presented in table 1, which contains a separate record for each of the 18 rats, and shows the average time taken by the animal when running in competition with each of the others with which it was paired. The results of the entire group are summarized in table 2, which shows the average running time for the rats when running alone and when pitted against others, and the reliability of the difference.

Although the average running time for the group is shorter in the competitive running than in the running alone, the difference in the averages is found to be unreliable. In fact, examination of the table for the individual animals will reveal that 6 of the 18 rats (nos. 1, 5, 6, 15, 16, and 20) ran faster on the average when running alone than when pitted against another animal. The effect of competition upon these animals was inhibitory, it would seem. A surveillance of the behavior protocols corroborates it. All of them, but to a more marked degree nos. 5, 6, and 16, remained in the entrance compartment for increasingly longer periods, and if they did venture out, usually returned within a few seconds or failed to move at all. On a number of

TABLE 1

The average speed of running of each rat when tested alone and when competing against other rats in the runway, together with the percentage of winnings and ties

RAT	ALONE	IN COMPETITION	PER CENT WINNINGS	PER CENT TIED
	sec.	sec.		
1	8.2	13.25	33	4
2	15.2	4.70	74	11
3	16.2	15.87	23	1
4	16.8	5.18	68	13
5	5.2	42.57	15	0
6	30.8	32.00·	47	0
7	5.4	5.33	65	17
9	14.2	2.35	41	4
11	4.8	4.27	65	26
12	20.2	5.66	81	7
14	6.0	3.80	100	0
15	27.0	40.35	0	0
16	48.8	64.70	7	0
17	22.4	13.66	75	3
18	16.1	9.38	62	8
19	30.0	16.52	28	2
20	13.7	21.20	63	0
21	24.2	9.13	65	8
Average*........	16.26	14.43		
S.D.*..........	8.32	12.32		

* The scores for No. 16 being disproportionately large, were omitted in the calculation of these group scores.

TABLE 2

*The difference between the average time in running alone and in running in competition**

AVERAGE TIME WHEN RUNNING ALONE	AVERAGE TIME WHEN IN COMPETITION	DIFFERENCE	CRITICAL RATIO
seconds	seconds		
16.26	14.43	1.83	.51

* The averages for No. 16 were omitted in obtaining both averages, since they were considerably larger than those of the rest of the group, particularly in the competitive situation.

trials the animal had not reached the end of the runway during the allotted 2 minutes.

Table 1 presents the average running times for each rat in this experiment. In the first column are the averages for the animals running singly, and in the second column the averages when they are running in competing pairs. The third column shows the total percentage of winnings by each rat in the competitive situation, and in the fourth column are shown the percentages of trials in which the running scores were tied.

A comparison of the averages for the group in time taken for the single runs and in the time taken for the competing against other animals shows that in general the presence of a competing rat induced a greater speed of running. The difference between the two averages does not prove to be statistically reliable, as table 2 reveals.

The considerably greater variability of the performance in the competitive situation is to be noted. It strongly suggests that competition affected different rats in different ways, and this fact is further confirmed by the variability in the percentage of winnings in the competitive trials, which actually range from zero to 100 per cent. The number of rats that won over 50 per cent of the time is 10, or 56 per cent of the group. In general, those rats which were the most frequent winners were also the most likely to be tied by their competitors.

We will now turn our attention to the averages for the individual animals. Of the entire group of 18 rats, 12 or 67 per cent were running faster under competition than when alone. These rats were the most frequent winners, only 2 of the 12, namely nos. 9 and 19 winning less than 50 per cent of the time. The positive effects of competition are most marked in the cases of nos. 2, 4, 9, 14, 18, and 21, it will be observed.

There remain, however, the 6 rats whose running times were longer in the competitive situation than in isolation, and for whom, it would seem, the competition had an inhibitory effect. These animals are nos. 1, 5, 6, 15, 16, and 20 respectively. All have poor records in the percentage of winnings and ties, except no. 20, in whose case 63 per cent of wins are recorded. Rats

15 and 16, for example, have the lowest percentage of winnings in the group. The behavior protocols for these six rats further give evidence of the inhibitory effect of the competition. All, but to more marked degrees nos. 5, 6, and 15, remained in the entrance compartment for increasingly longer periods, even when the competitor was leaving the compartment upon the opening of the door. If they did enter the runway, they usually returned to the entrance compartment within a few seconds. Sometimes they characteristically ran a short distance down the runway, then turned back to the entrance compartment, and again ran down the runway and back, repeating this behavioral sequence 5 and 6 times before being removed at the end of the allotted 60 seconds. After a series of continual failures to reach the goal, these rats even refused to leave the entrance compartment for a number of consecutive trials.

The variability within each animal as it was transferred from competition with one rat to another is a significant part of the results. The evidence for this variability is presented in table 3, which contains a separate record for each rat in the form of a subdivision of the table. The first column shows the rat with which competitive running was tested. The letter "L" indicates competition with a cage mate, and the letter "N" competition with animals that were not cage mates. The second column shows the number of trials with each competitor; the third column the average running time in seconds when the rat was pitted against each of its competitors; and the fourth column the number of trials won in the race with each of the competitors.

That the rats varied in their average running time with their competitors is clearly revealed in table 3. The trials that each rat received in running alone reduced the speed to a point where no signs of improvement were apparent. The average speed of running was greater in the trials with the first competitor than in the isolated running in a surprising number of cases. This is true for six rats, namely nos. 1, 3, 5, 6, 15, and 16. Some of these, as already mentioned, continued to run more slowly throughout the competitive trials than they had when running alone, regardless of which rat was the competitor. More char-

TABLE 3

The record of each rat tested alone and with each of its competitors

RAT	CONDITION OF RUNNING	NUMBER OF TRIALS	AVERAGE TIME	NUMBER OF TRIALS WON
			sec.	
	Alone	10	8.2	
	With no. 2 (L)	12	20.2	1
	With no. 15 (N)	9	36.8	1 (tied 1)
	With no. 3 (L)	10	5.6	4
No. 1, male......	With no. 4 (L)	10	7.0	1 (tied 1)
	With no. 7 (N)	9	7.8	0
	With no. 5 (L)	10	4.3	10
	With no. 9 (N)	6	4.0	6
	With no. 14 (N)	10	16.3	2 (tied 1)
	Alone	10	15.2	
	With no. 1 (L)	12	8.5	11
	With no. 4 (L)	10	4.3	5 (tied 3)
No. 2, female....	With no. 5 (L)	10	3.6	10
	With no. 3 (L)	10	4.3	9
	With no. 7 (N)	10	3.8	5 (tied 3)
	With no. 9 (N)	10	4.5	7 (tied 1)
	With no. 14 (N)	10	3.9	6 (tied 1)
	Alone	10	16.2	
	With no. 5 (L)	8	25.7	4
	With no. 1 (L)	10	14.7	5 (tied 1)
	With no. 6 (N)	9	7.6	5
No. 3, male......	With no. 4 (L)	8	7.3	1
	With no. 2 (L)	10	6.6	1
	With no. 7 (N)	10	21.8	0
	With no. 9 (N)	10	27.4	0
	Alone	10	16.8	
	With no. 3 (L)	8	4.8	7
No. 4, female....	With no. 5 (L)	9	6.7	8
	With no. 2 (L)	10	4.7	2 (tied 4)
	With no. 1 (L)	10	4.5	8 (tied 1)
	Alone	10	5.2	
	With no. 3 (L)	6	12.3	3
	With no. 4 (L)	9	39.7	1
No. 5, female....	With no. 7 (N)	10	41.7	1
	With no. 2 (L)	10	60.0	0
	With no. 6 (N)	10	41.7	3
	With no. 1 (L)	10	60.0	0

TABLE 3—*Continued*

RAT	CONDITION OF RUNNING	NUMBER OF TRIALS	AVERAGE TIME	NUMBER OF TRIALS WON
			sec.	
No. 6, male......	Alone	10	30.8	
	With no. 5 (N)	10	31.8	7
	With no. 8 (L)	5	32.2	0
	Alone	10	5.4	
	With no. 5 (N)	10	5.2	9
	With no. 1 (N)	10	3.9	10
No. 7, male......	With no. 2 (N)	10	10.7	0 (tied 5)
	With no. 3 (N)	10	4.0	10
	With no. 14 (L)	10	4.1	0 (tied 5)
	With no. 15 (L)	10	4.1	10
	Alone	10	14.2	
	With no. 1 (N)	6	13.8	0
No. 9, female....	With no. 2 (N)	10	17.6	2 (tied 1)
	With no. 3 (N)	10	5.2	10
	With no. 14 (N)	3	58.3	0
	Alone	10	4.8	
No. 11, female...	With no. 9 (L)	3	4.3	3
	With no. 1 (N)	10	5.3	7 (tied 1)
	With no. 7 (L)	10	3.2	5 (tied 5)
	Alone	10	20.2	
	With no. 21 (N)	10	3.8	10
	With no. 16 (N)	6	4.0	6
No. 12, male.....	With no. 19 (N)	10	12.9	6
	With no. 17 (N)	6	3.8	5
	With no. 18 (N)	10	3.9	7 (tied 3)
	Alone	12	6.0	
No. 14, male....	With no. 15 (L)	5	3.7	5
	With no. 13 (L)	5	3.9	5
	Alone	10	27.0	
No. 15, female...	With no. 14 (L)	5	36.1	0
	With no. 13 (L)	5	44.6	0
	Alone	10	48.8	
	With no. 20 (N)	3	63.2	3
	With no. 21 (N)	10	82.7	0
No. 16, female...	With no. 12 (N)	6	90.0	0
	With no. 18 (L)	10	90.8	0
	With no. 17 (L)	10	75.3	0
	With no. 19 (L)	6	67.5	0

13

TABLE 3—*Concluded*

RAT	CONDITION OF RUNNING	NUMBER OF TRIALS	AVERAGE TIME	NUMBER OF TRIALS WON
			sec.	
	Alone	10	22.4	
	With no. 16 (L)	10	8.8	10
No. 17, female...	With no. 12 (N)	6	14.7	1
	With no. 19 (L)	10	7.3	8 (tied 1)
	With no. 18 (L)	10	37.5	0
	Alone	10	16.1	
	With no. 16 (L)	10	5.4	10
No. 18, female...	With no. 21 (N)	10	7.6	3 (tied 1)
	With no. 12 (N)	10	24.1	0 (tied 3)
	With no. 19 (L)	10	6.0	8
	With no. 17 (L)	10	3.8	10
	Alone	10	30.0	
	With no. 21 (N)	10	17.3	0
No. 19, female...	With no. 12 (N)	10	19.7	4
	With no. 18 (L)	10	9.0	2
	With no. 17 (L)	10	28.3	1 (tied 1)
	With no. 16 (L)	6	8.3	6
	Alone	11	13.7	
No. 20, male.....	With no. 22 (L)	5	30.4	5
	With no. 16 (N)	3	120.0	0
	Alone	10	24.2	
	With no. 16 (N)	10	7.0	10
No. 21, male.....	With no. 12 (N)	10	13.5	0 (tied 2)
	With no. 19 (N)	10	5.0	10
	With no. 18 (N)	10	11.0	6 (tied 1)

acteristic of the animal, however, was the tendency to react differently to its various competitors, with the result that sometimes the average speed was considerably faster with one competitor than with the other. This strongly suggests that the animals were responding to each other as distinct individuals and not as general representatives of the species. No consistent difference between the effects of competing against cage mates and of competing against non-cage mates were found. It is probable, therefore, that contact with cage mates did not play a

deciding rôle in the orientation of the rats to the competitive task.

When two rats closely matched in their speed of running were pitted against each other, there is evidence that the competitive urge was most strongly elicited. This resulted in frequent ties or near ties. Sometimes the animals left the entrance compartment at the same time, and throughout their route to the goal box were running almost abreast, and therefore crowded each other to pass through the door of the goal compartment together. But at other times however, one rat left the entrance compartment before the other, and might have a head start of as much as 15 inches by the time that the other left the entrance compartment. The latter would then leap forward in an effort to overtake his rival. A tie occurred when the rat last to start down the runway ran or leaped fast enough to catch up with the one who started first, so that they pushed into the goal box together.

In the case of a number of closely matched pairs, the member which was slower in starting than the other, leaped or galloped down the runway in his effort to overtake his competitor. The two animals tied in this way naturally had access to the one piece of food in the goal box. Usually one seized it first, but was soon challenged by the other, who nudged, pushed, climbed over his rival, or even bit him in his attempts to get food. Frequent squeals were heard as they pushed and bit each other. Sometimes they broke the piece of bread into two small bits, with each one devouring his separate portion.

It will be noted that most of the rats scored tie runs with at least one of their competitors. The notable exceptions are nos. 5 and 6, whose reactions to frustrations have already been described, and nos. 14, 15, and 16. Of the entire group no. 2 tied with the greatest number of its competitors, while no. 7 tied the largest number of times, but always with the same two competing animals.

The opportunity for the loser to see the winner devour the food in the goal box seems to have produced aggressive behavior in the former in many instances, especially when the competitors

had been closely matched in their runs down the runway. Such forms of behavior as scratching and biting at the door of the goal box, or even striving to climb over the top of it, occurred. Sometimes the loser would remain in front of the door for as long as 30 seconds or until the experimenter removed the winner from the goal box. The writer believes that the observing of the winner eating the food enhanced the competitive urge of the loser, although it is admittedly difficult to give quantitative proof. Highly competitive animals also bit and clawed at the door leading from the entrance compartment to the runway as they prepared to rush forward down the runway. The highly competitive ones were not observed to give much attention to each other in the entrance compartment, in spite of the fact that they could see each other through the transparent partition. In fact, it was rats that were less positively responsive to competition that watched their competitors in the other side of the compartment. When the entrance door was opened, the two rats would meet each other and sniff, or even run from one another's side of the entrance compartment to the other's. Highly competitive rats occasionally sniffed each other's bodies as they left the entrance compartment, but more frequently dashed down the runway without any preliminary bodily contact.

C. EXPERIMENT II. COMPETITION

A second experimental situation to test competition consisted of using two elevated mazes of identical design. These were placed together at their ends so that the two correct pathways converged upon a common goal. The entrances of the two mazes were separated by a distance of 40 inches. Thus the competing animals were throughout most of their course of running in the maze gradually coming closer and closer together until they finally met at the goal. The correct paths of the two mazes, the design of which is shown in figure 2, were $89\frac{1}{4}$ inches in their total lengths. There were eight blind alleys, it will be seen, and all of the turns were right angle turns. The wooden strips out of which the maze was constructed were $1\frac{3}{4}$ inches in width and raised 20 inches above the floor.

Nine rats that had previously learned this maze pattern, i.e., had attained a norm of mastery of 4 errorless runs out of 5, and likewise were running at a nearly constant rate of speed, were the subjects.   The effects of competition were studied by simultaneously placing each member of the competitive pair at the entrances of the two mazes and measuring the time taken to reach the goal.   Any errors made by the animals were noted and considered to be indications of possible disturbances created by the competitive situation.   In as much as there was only one piece of food at the one goal, the faster runner would be the one to get it.   The loser, however, might be able by aggressive
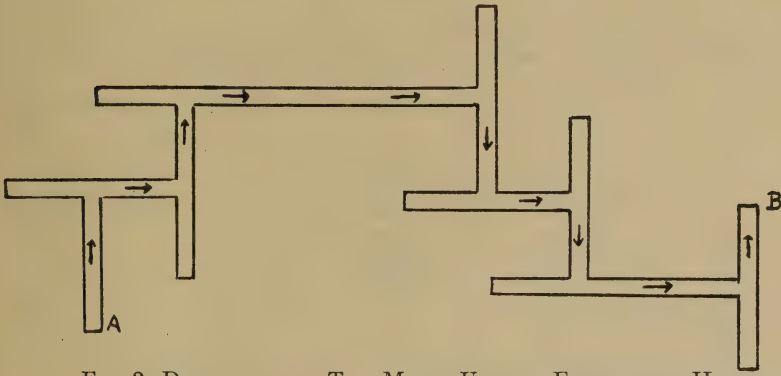
FIG. 2. DESIGN OF THE TWO MAZES USED IN EXPERIMENT II
A, entrance point; B, the goal point where piece of food was placed.   Arrows indicate the route of the correct pathway.

attacks upon the winner to grab the whole piece of food (whole wheat bread) or part of it.   This situation, therefore, unlike the previous one, provided for actual contact between the winner and loser, and consequently the opportunity for the experimenter to observe the amount of aggressiveness exhibited by each of the losing members of a pair.   Three or four trials were given at each testing period, and the rats had not received food for 24 hours previously.   The rats were trained and tested interchangeably on the two mazes in order to accustom them to anticipate the food at the end of the final turn either to the right or to the left, since the common goal of the two mazes was approached from two different directions.

The average time taken by each rat in running the maze alone, the total average time for each rat in competition, the total percentage of winnings when pitted against its several competitors, and the total percentage of ties are presented in table 4. The difference between the average time spent in running the maze alone and running it in competition with another is a large one, but one that cannot be tested for statistical reliability because of the small size of the group. It will be noted, however, that three of the seven rats, namely nos. 1, 3, and 11, actually ran slower on the average in the competitive situation than

TABLE 4

The average speed of maze running in each rat when tested alone and when competing against other rats, together with the percentage of winnings and ties*

RAT	ALONE	IN COMPETITION	PER CENT WINNINGS	PER CENT TIES
	sec.	*sec.*		
1	5.7	8.28	20	0
2	6.3	5.80	41	2
3	4.3	5.28	51	2
7	15.5	6.02	84	2
9	11.0	7.53	46	0
10	37.0	13.70	10	0
11	4.6	4.77	69	4
Average.........	12.06	7.34		
S.D............	10.85	2.82		

* The scores of the two rats 5 and 6 are omitted because of their constant refusal to run the maze after the first few trials.

alone. The difference in the case of no. 11 is, of course, very small. The scores of rats 5 and 6 are necessarily omitted because of their refusal to run the maze either singly or in competition.

As in the preceding experiment, competition seems to have had two alternative effects—either to produce greater efforts in the performance of the task, or to inhibit them as a result of the frustration. The percentage of winnings for the animals that ran slower in competition than alone are not consistently smaller than the percentage for those that ran faster, although the highest score was obtained by a rat affected positively by the competition,

no. 7. The second highest percentage, however, was obtained
by rat 11, one that tended to be somewhat inhibited by the
competition. It was this same animal, it will be noted, that
tied its competitors the most frequently.

In table 5 are presented for each rat the number of trials run in
isolation and in a pair against each of its competitors; the average
running time with each of its competitors; the number of errors
(entrances into blind-alleys) made when running in isolation and
with the several competitors; and finally the total number of
trials won when pitted against each of the competitors.

The records for all of the rats show that speed of running
varied considerably from competition with one animal to com-
petition with another.   This variability is not so great, however,
as in the first experimental situation.   The variability of no. 9
in its speed of running against its different competitors is perhaps
the most marked of the group.

The effect of frequently winning over a competitor upon the
speed of running can be observed from a comparison of the scores
in the column labelled "number of trials won" with the average
speed of running against the different competitors.   In general,
each rat seems to have run faster when it was pitted against
another rat over which it was winning a large proportion of the
time.   This is most clearly demonstrated in the case of rat no. 7,
which had the highest percentage of winnings of the entire group.
Likewise, with no. 3 the average running time was shortest in
competition with no. 2 when it won in all of the ten trials, and
somewhat slower when it was winning in only a small percentage
of them.

The number of trials in which the rats tied in their speeds of
running are strikingly few.   Only four of the seven rats scored
a tie at all, and these only once.   The retardation in running
resulting from the numerous turns in the correct pathway of the
maze probably decreased the possibility of two rats completing
the pathway in exactly the same time.   Furthermore, the greater
distance of the running animals from each other may not have
incited them to run abreast of each other as they could and did
in the straight runway in Experiment I.   It would also be more

TABLE 5

The record of each rat when tested alone and with each of its competitors

RAT	CONDITIONS OF RUNNING	NUMBER OF TRIALS	AVERAGE TIME	TOTAL NUMBER OF ERRORS	NUMBER OF TRIALS WON
			sec.		
No. 1, male......	Alone	12	5.7	2	
	With no. 9 (N)	10	9.9	4	2
	With no. 3 (L)	5	5.3	2	2
	With no. 7 (N)	10	9.5	1	0
	With no. 2 (L)	10	11.0	3	2
	With no. 11 (N)	10	5.7	1	3
No. 2, male......	Alone	6	6.3	2	
	With no. 7 (N)	10	5.4	1	5
	With no. 3 (L)	10	5.3	1	0
	With no. 1 (L)	10	9.0	4	7
	With no. 11 (N)	6	5.5	2	1 (tied 1)
	With no. 9 (N)	10	3.8	0	6
No. 3, male......	Alone	10	4.3	0	
	With no. 1 (L)	5	4.7	0	3
	With no. 2 (L)	10	4.3	0	10
	With no. 6 (N)	5	7.5	3	5
	With no. 9 (N)	5	5.3	0	2
	With no. 11 (N)	10	4.4	0	3
	With no. 7 (N)	10	5.5	2	0 (tied 1)
No. 7, female....	Alone	10	15.5	8	
	With no. 2 (N)	10	12.3	1	5
	With no. 1 (N)	10	5.0	0	10
	With no. 9 (L)	10	4.5	1	9
	With no. 3 (N)	10	4.0	0	9 (tied 1)
	With no. 10 (L)	10	4.3	0	9
No. 9, female....	Alone	10	11.0	6	
	With no. 1 (N)	10	8.2	2	8
	With no. 3 (N)	5	4.7	0	3
	With no. 7 (L)	10	12.6	0	1
	With no. 2 (N)	10	4.6	0	4
No. 10, female...	Alone	20	37.0	22	
	With no. 7 (L)	10	13.7	5	1
No. 11, female...	Alone	10	4.6	1	
	With no. 2 (N)	6	4.5	1	4 (tied 1)
	With no. 3 (N)	10	4.7	0	7
	With no. 1 (N)	10	5.1	0	7

difficult for a rat slow in starting to overtake its rival because of the turns in the maze pathway.

That this competitive situation not only produced inhibitory effects in some animals, but also disruptive effects, is evidenced by the number of errors incurred in competition. Rat 1 was the most consistent in making errors in its running against its competitors, with no. 2 the next in order. It will also be noted that no. 1 won only a small percentage of its competitive trials, 20 per cent. It might be argued that if a rat found in a series of repeated runs that it did not get food, the food would tend to decrease in its demandedness, wth the result that the blind alleys might be more attractive than they would be to a winning rat. Tolman, Honzik, and Robinson (13), for example, have reported that less hungry rats tend to enter long blind alleys in preference to short ones, since the exploratory demand is probably stronger than the food one. Tolman and Honzik (12) also have found that less hungry rats fail to eliminate blind alleys as quickly as the more hungry rats.

Behavior protocols reveal many examples of fighting between members of the competing pairs in the mazes. Since both animals actually reached the goal, the loser could attack the winner, and even pursue it over the maze pathway. When two animals were closely matched in running speed, aggressiveness was more frequent and more severe than when they were unevenly matched. The fighting usually started with the loser's attempt to seize the food from the winner. Thereupon, the winner suddenly turned around with the piece of bread in its mouth so that its rival could not reach it. An aggressive loser would then nudge on the body of the winner in its attempt to push itself alongside of the other rat so that it would be in a position to snatch the food again. If it was successful, head to head fighting occurred whenever the winner resisted, each pushing the other or both pulling on the food simultaneously. In this way the loser frequently succeeded in getting a piece of the bread, and the struggle was ended, each rat having devoured its small piece of food. Sometimes, however, the winner began to run back over the maze as soon as the loser began to nudge from behind, to be

followed by the loser in pursuit. If the latter caught up with the winner before it could finish eating the piece of bread, the nudging and pushing occurred in the manner just described. Sometimes the pursuit of the winner by the loser lasted for more than a minute, the one chasing the other over the maze several times. Although the winner generally led the chase over the correct pathway, the occasional entrances into blind alleys tempted the experimenter to say that the winner was trying to elude its pursuer. Rats 3, 7, and 11 were the most aggressive when either losing or winning, and when pitted against each other pursued and attacked vigorously.

There was some evidence that the competitive behavior of the first few trials in some pairs of rats gave way to altruistic food-sharing in the later trials, as demonstrated by Mowrer (9) in his film entitled *Social modification of organically motivated behavior*. Competitive behavior, however, was on the whole more common than altruism.

D. EXPERIMENT III.   COÖPERATION

As previously mentioned in the Introduction, the writer considers that coöperative behavior involves an active striving on the part of two or more individuals to secure a goal-object that each individually desires to secure, but cannot do so because of its unattainability by a single individual. The food-sharing by rats which Mowrer (9) has called "altruistic" behavior does not connote the goal-directed behavior nor the possible reasoning that are inherent aspects of coöperation, the writer believes.

The rat's ability to coöperate was tested experimentally in a situation that required one animal to work conjointly with another to obtain a piece of food. A diagram of the apparatus is shown in figure 3. The box inside of which the rat was placed for the tests was 12 inches long, 7 inches wide, and $6\frac{1}{4}$ inches high. The problem set for the animal was to pull a string which formed a continuous circuit from a pulley 9 inches above the top of the box to a pulley just under the floor of the box. The rat secured the food, a small piece of carrot, clipped to the string, by standing on its hind legs and reaching up to grasp the string

in the forepaws, in which position it was able to pull the string a considerable distance with repeated "heave-ho" movements until the carrot was within reach. As a first step in the training the rat learned to pull the string, first only $\frac{1}{2}$ inch, and then progressively more, until it was pulling the string the total
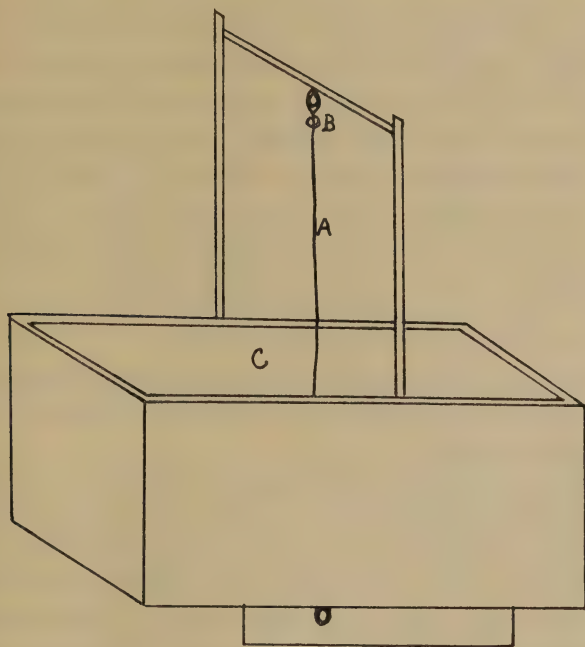
FIG. 3. STRING-PULLING APPARATUS IN EXPERIMENT III

A, the string running on a continuous pulley from the top of the apparatus to a point under the floor of the box; *B,* the piece of carrot clipped to the string 9 inches above the top of the box; *C,* the inside of the box in which rat stood when pulling the string.

$8\frac{1}{2}$ inches to get the piece of carrot when it was attached to the top of the string.

After each rat had acquired the string-pulling habit in this way, a variable weight was fastened to the string on the other side of the pulley-circuit. This weight could gradually be increased by the addition of B-B shots until the threshold for weight pulling had been reached for each rat individually, as judged by the inability of the animal to pull the weight for six consecutive

trials.   After the threshold for each rat working alone was obtained, the weight on the string was further increased to make it about one-sixth times heavier than the determined threshold for the individual animal.   The rat was then tested alone to see if it could pull the above-threshold weight, and if not, after four consecutive trials, it was judged that the weight was distinctly above the rat's weight-pulling threshold.   Thereupon two rats nearly equally matched in their individual threshold strengths were put into the box together in order to test whether they would at any time pull the string together, and thereby coöperatively combine their pulling strengths to obtain the desired food.

Each rat was weighed about every two weeks, so that an estimation of the size of the weight that it would probably be able to pull could be made.   The animals, deprived of food for 24 hours preceding an experimental period, were given three or four trials during each experimental period.

The subjects for the experiment were nine rats, eight of which had been tested previously in Experiment I, and the other, no. 13, in Experiment II.

In table 6 are presented the results for each rat, including the number of trials each received alone in the box and the number received when paired with each of the other rats whose numbers are designated in the first column; the range of the weights in grams pulled when alone and when paired with another; and finally the number of times that the rat secured the food.   The respective average weights of each rat during the experiment appear at the heading of each part of the table.   No quantitative data concerning coöperation are indicated in the table, in as much as the results were so completely negative when viewed from this angle.   In fact, the results reveal evidences of competition instead, and the summary of the scores as presented in table 7 treats them from the viewpoint that the rats were responding to each other competitively.   Only eight times in the course of the entire series of trials with the nine rats in pairs did two animals pull on the string together for more than a second. But these occasions were considered to be more or less coincidental by the writer, since at the most any two rats pulled

TABLE 6

The record of each rat when tested alone and with each of its competitors

RAT	CONDITIONS OF RUNNING	NUMBER OF TRIALS	WEIGHT PULLED	NUMBER OF TIMES RAT SUCCEEDED IN GETTING FOOD
			grams	
	Alone	14	14.6–19	13
	With no. 15 (L)	12	23.0–28.0	9
	With no. 14 (L)	10	33.0–38.0	2
	Alone	45	23.0–32.0	29
	With no. 21 (N)	12	32.0–34.0	3 (tied 1)
No. 12, male, average weight 107.7 grams	Alone	3	34.0	0
	With no. 18	6	32.0	2
	Alone	6	34.0	6
	With no. 16 (N)	6	34.0	6
	With untrained (N)	3	34.0	3
	With no. 19 (N)	6	34.0	3
	With no. 17 (N)	3	34.0	3
No. 13, female, average weight 161.3 grams	Alone	45	14.6–45.0	44
	With no. 14 (L)	10	45.0	0
	With no. 25 (L)	3	45.0	2
	Alone	31	14.6–35.0	30
No. 14, male, average weight 152.5 grams	With no. 12 (L)	10	33.0–38.0	8
	With no. 15 (L)	10	36.0–38.0	10
	Alone	9	38.0	8
	With no. 13 (L)	10	45.0	10
	Alone	3	45.0	3
	Alone	15	14.6–21.0	12
No. 15, female, average weight 117.8 grams	With no. 12 (L)	12	23.1–28.0	3
	With no. 14 (L)	10	36.0–38.0	0
	Alone	5	38.0	1
	With no. 13 (L)	3	45.0	1
	Alone	3	38.0	1
	Alone	78	11.3–25.0	69
	With no. 18 (L)	10	32.0–34.0	3
No. 16, female, average weight 128.1 grams	With no. 12 (N)	6	34.0	0
	Alone	6	34.0	0
	With no. 21 (N)	6	32.0–34.0	0
	With no. 17 (L)	3	34.0	0
	With no. 19 (L)	6	34.0	0
	Alone	3	34.0	0

TABLE 6—*Concluded*

RAT	CONDITIONS OF RUNNING	NUM-BER OF TRIALS	WEIGHT PULLED	NUMBER OF TIMES RAT SUCCEEDED IN GETTING FOOD
			grams	
No. 17, female, average weight 85.5 grams	Alone	52	11.3–26.0	47
	With no. 19 (L)	10	30.0	1
	Alone	3	30.0	0
	With untrained (N)	3	30.0	0
	With no. 16 (L)	3	34.0	0
	With no. 12 (N)	3	34.0	0
	With no. 18 (L)	6	34.0	0
No. 18, female, average weight 113.8 grams	Alone	70	11.3–28.0	69
	With no. 16 (L)	10	32.0–34.0	7
	With no. 12 (N)	6	32.0	4
	Alone	3	32.0	3
	With no. 21 (N)	6	34.0	4
	Alone	9	34.0	8
	With no. 17 (L)	6	34.0	4
No. 19, female, average weight 92.8 grams	Alone	62	11.3–28.0	60
	With no. 17 (L)	10	30.0	9
	Alone	3	30.0	3
	With no. 12 (N)	6	34.0	3
	With no. 16 (L)	6	34.0	6
No. 21, male, average weight 142.7 grams	Alone	39	11.3–26.0	36
	With no. 12 (N)	12	32.0–34.0	8 (tied 1)
	Alone	3	34.0	3
	With no. 18 (L)	6	34.0	2
	With no. 16	6	34.0	5

together no more than twice, and at no time was the joint pulling followed up by other similar performances.

In as much as the effects of competition began to appear in the results, the writer decided to intersperse among the trials in which the rats were paired occasional trials in which the rats were tested singly, in order to determine whether the competition had produced effects beyond the immediate ones evidenced in the tests with the competing pairs. The average weights that were pulled in these interspersed trials are also presented in table 6.

When the average maximum weights pulled by each rat tested alone are compared with the average maximum weights pulled when the rats were working in pairs (table 7), it will be observed that the rats were almost constantly pulling heavier weights when they were paired with another rat. The only rat that failed to pull a heavier weight when paired than when alone, no. 13, pulled the same weight under both experimental conditions. These scores substantiate the writer's point of view that the pairing of the rats in the box induced competitive behavior instead of coöperative. Rats 12, 15, and 17 seem to have re-

TABLE 7

Comparing the average maximum weights pulled by each rat when working alone and when working in the presence of another rat

RAT	WHEN WORKING ALONE	WHEN WORKING IN THE PRESENCE OF ANOTHER
	grams	grams
12	28.3	33.5
13	45.0	45.0
14	39.3	40.3
15	32.3	37.0
16	31.0	34.0
17	28.0	32.4
18	31.3	33.5
19	29.0	32.7
21	30.0	34.0
Average..............	32.70	35.82
S.D...................	5.40	4.01

sponded most effectively to their competitors, as the large differences between the weights that they pulled when paired with another animal and the weights pulled when they worked alone show.

The effects of competition can be more minutely studied by examination of the records for the individual animals in table 6. Some of the rats were considerably more consistent than others in being the first to pull the string with the weight attached. The animals most consistent in this respect were nos. 14, 18, and 21. The interpretation seems justified that these rats were

responding competitively. Rat 21 even pulled a heavier weight with its later competitors than with the earlier ones. The rats that secured the food the fewest number of times, notably nos. 15, 16, and 17, were inhibited in their reactions to pulling the weight, the writer believes. After failing to get the piece of carrot for several consecutive trials, these animals usually desisted from any further pulling on the string. The inhibition was carried over to the later trials when they were tested alone in the box, as the few number of times that they secured the food shows. After failing to obtain the food from their first competitors several times, rats 16 and 17 seem to have become almost entirely inhibited in any effort to try to win over any of their later competitors, since after the first only occasional attempts to pull the weight occurred.

Although the animals varied in their efforts to secure the food from one competitor to another, the variability was not so great as was found in the same rats in Experiments I and II. Rats 12 and 13 were the most variable, it will be seen.

Apparently no distinction was made between other rats that were untrained, and hence not rivals for the privilege of pulling the string to get the food, and those rats that had previously been trained to pull the string, and could thus be real competitors. It must be conceded, however, that the data which would permit such a comparison are meager.

This experimental situation provided for close contact between the rats when they were paired in the small box. In fact, the food-securing task, unlike the corresponding ones in Experiments I and II, was performed by one rat in the presence of the other. It would even be possible for the rat that did not first attempt to pull the string to prevent its competitor from doing so by such acts as pushing or pulling the other. No interference of this kind was ever observed, and the conclusion that it, as well as coöperative behavior require foresight or reasoning that is beyond the psychical powers of the rat seems justified.

After the winner had secured the piece of carrot, the loser, if it responded positively to the competitive situation, frequently rushed to the winner, seized one end of the piece of carrot, and

pushed or nudged its rival.   If it failed in this way to get a piece of the carrot, it would continue to pursue the winner until in a number of instances it did get a piece of the food.   The winner would frequently run round and round the box to elude its pursuer, pausing for a moment at intervals to nibble on the carrot, if possible.   Those rats that responded with inhibition to the competitor seemed to pay no attention to the piece of carrot or the winner.   They preened themselves or sluggishly remained in one corner of the box.

Every one of the nine rats several times at least showed food-sharing behavior analogous to what Mowrer (9) has called "altruism."   It generally appeared after a number of trials of competitive struggle over the food by the pair of rats.   Thereafter the rat that pulled the weight to get the piece of carrot allowed its rival to take some of it without any overt signs of resistance.   The resistance on the part of the winner usually reappeared as soon as it was paired in the box with another competitor, to be followed by food-sharing in the later trials.

The size of the rats seems to have been of secondary importance in determining the amount of response to a competitor. In fact, the smallest rats, nos. 17 and 19, with body weights of 85.5 grams and 92.8 grams, respectively, in competition pulled weights as heavy as some of the rats that were considerably larger than they were, such as no. 21, with a body weight of 142.7 grams and no. 16 with a body weight of 128.1 grams.   To be sure, the heaviest rat of the group, no. 14, with a body weight of 152.5 grams, pulled the heaviest weight of the group, but this was an exceptional rather than a typical case.

In so far as the writer could observe, the reaction of two cage mates toward each other in the experimental situation did not differ from the reactions of non-cage mates.

E. DISCUSSION AND CONCLUSIONS

The results from all three of the experimental situations indicate that paired rats responded to each other as if they were competitors for a single piece of food.   In the first two experiments the rat's speed of running determined whether it would

win by reaching the food first. In Experiment I the winner, once it had seized the food in the goal-box, was not faced with the possible loss of all or part of it unless the competitor succeeded in reaching the goal compartment door at the same time, in which case the two animals became competitors for the same piece of food. In Experiment II, however, the winning rat, even after it had reached the food at the end of the maze, was never safe from the attacks of its losing opponent. It, therefore, seems natural that more dramatic competitive behavior of pursuing and fighting would be observed in Experiment II.

The experimenter noted during all of the tests of competition in all of the three situations that the amount of fighting for food in the living cages was obviously increased, but was increased most markedly during the general period of time when tests with the two mazes in Experiment II were being given.

Although the string-pulling situation in Experiment III proved to be one that elicited competition instead of coöperation, the effects of the competition were manifested in a different way from that found in Experiments I and II. The problem-solving task of pulling the weighted string to get the food did not in itself induce competitive pulling in the pair of rats in the box, but the possession of the food by the winner after it had pulled the string definitely served to evoke pursuit, pushing, and nudging from the opposing rat. In fact, many times the opposing rat was observed to pull on the string alone a number of seconds after the winner had pulled and obtained the piece of carrot. Apparently the connection between pulling the string and securing the piece of carrot was beyond the comprehension of the observing animal, so that competition was really not induced until the observing rat had actually seen the piece of carrot in the possession of its opponent.

The question as to whether the rats were consistently different one from the other in the way that they responded to a competitor will now be considered. The data provide information pertinent to this point, in as much as the same rats were generally used as subjects in two of the three experiments. The results show that some animals consistently ran faster or pulled harder under the

threat of competition from another.   Rats 1, 2, 3, 5, 6, 7, 9, and 11 were used as subjects in both Experiments I and II.   By comparing the scores for these respective rats in table 4 with those in table 1 it is possible to observe the consistency of the rats' behavior under competition in the two experimental situations.   Of the entire group rat 9 ran the fastest in Experiment I, and showed proportionately the greatest amount of positive effect from the competition, its average running time when pitted against other rats being 2.35 seconds as compared with the average of 14.2 seconds when running alone.   This same animal in Experiment II was by no means the fastest runner of the group either alone or in competition, but it continued to show to a marked degree the positive effects of competition.   The rat that ran the fastest under competition in the two maze situation was no. 11, and it will be observed from table 1 that this animal had run very fast on the average in Experiment I, occupying second place in the group in its speed of running.   In Experiment I, however, the difference between its speed of running alone and in competition is exceedingly small, although slightly faster in the competition, whereas in Experiment II, the difference, likewise exceedingly small, is a difference resulting from a faster speed when running alone than when running in competition.   The small difference between the speed of running scores in the two experiments indicates a consistently weak response of this rat to competition, although it was a fast runner.   Rat 7 showed positive effects of competition in both experimental situations, although the difference between its speed of running in isolation and in competition is smaller in Experiment I.

A similar consistency in those rats that responded with inhibition to the competitive situations of Experiments I and II can be observed.   For example, rats 5 and 6 had become increasingly less and less motivated to run down the runway in Experiment I when pitted against any competitor, as the experiment progressed, and were only occasionally moving down the runway at all when pitted against their last competitors.   In the mazes of Experiment II these same rats showed such marked inhibition to running, as was mentioned in Part C, that the

experimenter finally had to drop them as subjects. Even when tested alone on the maze, they tended to remain at the entrance point, or at the most, to move over only one or two sections of the maze, at the end of which they would remain motionless for several minutes before being removed by the experimenter.

Further evidence for consistency in the responses to competition can be obtained through a comparison of the records of those rats that were subjects in both Experiments I and III, namely the eight rats, nos. 12, 14, 15, 16, 17, 18, 19, and 21. Examination of the individual scores in tables 1 and 7 reveals that no. 12 was the rat that showed the greatest difference between its speed of running in competition and in running alone in Experiment I, and likewise, was the rat that showed the greatest difference between its weight pulling score when tested in competition and when tested alone. Closely corresponding positions in the amount of positive response to competition in the two sets of scores in Experiments I and III were obtained by rats 17, 18, 19, and 21, it will be noted.

The lack of consistency is most obvious in the cases of rats 15 and 16. Although both of these animals seem to have responded to competition in Experiment I by inhibition of their speeds of running, in Experiment III they were induced to pull weights considerably heavier when pulling in competition than when pulling alone.

Although some reference has already been made to the possible relationship between the physique of the animals and their responsiveness to competition, further points might be considered, the writer believes. In respect to size, it was observed in general that smaller rats were induced to run faster and pull harder through the presence of a competitor than were large rats. In fact, those rats that reacted with the most marked inhibition, nos. 5 and 6, were the largest rats of the entire group. Both could be characterized as having slow tempos of activity even when observed outside of the experimental situations, and as having shown very little activity even when alone in the experiment. They became increasingly resistant to running when pitted against competitors, as the writer has previously men-

tioned.   The smaller rats had a faster tempo and what might be called a stronger drive, for even when they were placed in the entrance compartment of the apparatus in Experiment I, they were continually moving about, turning round and round, or climbing and sniffing the walls.

It can be stated that no consistent sex difference was found. The average competition scores of the two sexes in the three experiments are as follows:

	MALES	FEMALES
Experiment I................	13.26 sec.	20.36 sec.
Experiment II..............	6.53 sec.	7.95 sec.
Experiment III.............	35.9 gr.	35.80 gr.

The two animals that ran the fastest under competition in Experiment I, nos. 9 and 11, were both females, but of the two rats most inhibited by the competitive situation, nos. 5 and 6, one was male and one was female.

The results in general lead the author to conclude that the rats showed competitive behavior in all of the three experimental situations included in the study, three situations that required three different kinds of performance on the part of the rats. The active striving, the increased speeds of running, the heavier weights pulled, and especially the intensive fighting which ensued, preclude an interpretation of the results in terms of "group facilitation," the writer maintains.   The responses of withdrawal and refusal to run or pull on the string in losing rats further indicates the inadequacy of a "group facilitation" explanation. Both general types of response should be attributed to the operation of an active competitive drive that the rats possessed in varying degrees.   This drive was aroused to a high level through the frustration of hunger satisfaction that a competitor threatened.   That this frustration would sometimes cause a reduction in the amount of effort a rat would use in trying to get the food, as well as an increase, seems to be clearly evident in the scores and the behavior of those rats that responded to competition by withdrawal and refusal to run or pull.

Although the results from one experiment cannot be considered conclusive, they strongly indicate that rats are incapable of "voluntary" coöperation. It would seem that the string-pulling situation in Experiment III closely approached an optimum for the elicitation of coöperative behavior in the rat.

More specifically stated, the following conclusions can be drawn from this experimental study:

1. Rats respond competitively to one another when they are rivals for a single piece of food.

2. The presence of competitors affects rats in one of two general ways: either to induce greater effort than is shown when they are tested singly; or to reduce the amount of effort, even to the point of refusal to perform in some instances. Continuous winning in general tends to produce the former type of response, and continuous losing the latter.

3. Individual differences are rather marked in rats in the kind and the amount of reaction to the presence of a competitor.

4. No consistent sex difference is found in the response to competition.

5. In so far as could be determined, cage mates differed in no apparent way from non-cage mates in the kind and the amount of response to competition, although more fighting over food in living cages containing competing rats was observed to occur.

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CONTENTS

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1

PREFACE

The present investigation into the nature of morphine addiction in chimpanzees was conducted at the Yale Laboratories of Primate Biology at Orange Park, Florida, during the years 1935–1937. The problem was originally suggested to the writer by Doctor Robert M. Yerkes, director of the laboratories, and was carried out under his administrative supervision.

The project enjoyed the coöperation and advice of the Committee on Drug Addiction of the National Research Council, and the United States Public Health Service, which, in addition to valuable suggestions, supplied the necessary drug. During its second year, the investigation was financed by a grant from the Josiah Macy Jr. Foundation.

The writer wishes to acknowledge his indebtedness to a number of persons without whose aid the project would have been much more difficult to carry through to a satisfactory conclusion.

Doctor Yerkes gave freely of his advice and suggestions during the planning and prosecution of the experiments, and also carried on the experimental regimen during a brief period when the writer was absent from the laboratories.

Doctors J. H. Elder and J. M. Bruhn of the laboratory staff aided the investigation in numerous ways, the latter making all the determinations of metabolic rate and blood cell counts reported in this study.

Doctors Lawrence Kolb, C. K. Himmelsbach, and others of the staff of the U. S. Public Health Service Hospital at Lexington, Kentucky, extended to the writer many important suggestions as well as a warm hospitality during his two visits to their institution to study human drug addicts, and on numerous other occasions.

Doctors L. R. Thompson and R. D. Lillie of the National Institute of Public Health (of the U. S. Public Health Service) directed and made a histological study of the brain of one of the morphine-addicted animals, comparing it with the brain of a normal chimpanzee.

Doctor L. Y. Dyrenforth, pathologist, of Jacksonville, Florida, generously performed important autopsy work on two of the animals used in this investigation, and Doctors E. C. Swift and W. M. Shaw, also of Jacksonville, gave freely of their time and advice during certain illnesses which the animals experienced.

Doctor Bruhn took the photographs for figures 1, 2, 3, and 8, Doctor Yerkes for figures 4 and 7, and Doctor Elder for figure 6.

PART I. INTRODUCTORY

A. CHRONIC MORPHINISM IN ANIMALS

1. Animals used as subjects

The use of animals in experiments on the effects of morphine and on the nature of morphinism has been of peculiar importance. In view of the risk of inducing addiction, investigators have been extremely loath to use human subjects in experiments which would require the repeated administration of opiates. Consequently, our knowledge concerning morphinism in man has been almost completely limited to observations made on clinical cases; i.e., persons who already have a well-developed drug addiction when first seen, and possibly other concomitant or predisposing pathology as well. Experimental work on this topic has thus been forced to utilize already addicted subjects, and has been largely limited to studies of continuing morphinism in the addicted human and to the effects of withdrawal from the drug. Data on the experimental induction of morphinism in man, although obviously of fundamental research importance, are conspicuously lacking. The human costs are felt to be too great.

For these reasons research on the fundamental nature of chronic morphinism, the appearance of tolerance, and the onset of addiction (if it appears), must be principally carried out with animals as subjects. The more closely the animal type chosen for such investigations resembles the human being in its general physiological and behavioral makeup, and also in those of its reactions to morphine which can be compared with human reactions, the more valuable will that animal type be for research on these problems.

The use of animals in experimental studies of opium and its derivatives can be traced back about three-quarters of a century. Bernard (1864) has been credited by several authorities with having given the first detailed report of the effects of morphine

5

on dogs.   There were a few scattered reports of experiments with
opiates on animals in the latter years of the nineteenth century,
but it is the past three decades that have seen the greatest num-
ber of studies in this field.   (For resumés, especially of the earlier
studies, see the reviews of Plant and Pierce, 1928, and Tatum,
Seevers, and Collins, 1929.)

Monkeys, dogs, cats, rabbits, rats, goats, pigeons, frogs and
other cold-blooded animals, as well as several other animal forms,
have   served   as   subjects   for   morphine   investigations.   Dogs,
cats, rabbits, and rats have been most commonly employed, al-
though recent years have seen an increasing tendency to use the
rhesus and other types of monkey, in the attempt to secure re-
sults more like the data which would presumably be forthcoming
if human subjects could be used in comparable experimental
procedures.

In general these studies have shown that with morphine, and
several of the other opiates, tolerance can be induced in most of
the warm-blooded animals, whereas cold-blooded animals, such
as the frog, appear to become more susceptible to the drug with
repeated doses.

The picture of morphine effects upon animal functions is a
highly complex one.   The size of the dose used, the frequency of
administration, and the rate of increase of the dose size are all
important factors; perhaps most important is the species which
is chosen as subject.   Different species show widely differing
responses to the same relative doses of morphine, and it is often
impossible or extremely difficult to predict specific effects in one
species on the basis of what is known of these effects in another
species.

For man, Sollman (1936), among others, has presented a fairly
complete picture of the clinical effects of single doses of morphine.
The symptoms of withdrawal have been described in detail by
Light et al. (1929) and more recently by Himmelsbach (1936).
The vast literature pertaining to the many aspects of human
drug addiction has been ably reviewed, up to the year 1928,
by Terry and Pellens (1928).

For the lower organisms the literature reveals a wide variety of

effects of opiates. Tatum, Seevers, and Collins (1929) have summarized the literature bearing on the effects of acute and chronic doses of morphine in dogs, rabbits, and cats, and have described their own experimental work with these animal types, as well as with monkeys. Plant and Pierce (1928) have presented a detailed description of their experiments on the effects of chronic morphinism and withdrawal on the general behavior and symptoms of dogs. Kolb and DuMez (1931) have described the effects of acute and chronic doses of morphine, heroine, and codeine on the monkeys with which they experimented. More recently Seevers (1936 a and b) has presented the results of extended experiments with monkeys, using morphine, heroine, and dilaudid.

In addition to these inclusive reports, the literature contains many others which have concerned themselves with more restricted aspects of the problem, and have contributed data to various specific questions. In the experimental sections of the present report, the results secured will be compared with those of comparable studies on other warm-blooded animal forms and with the relevant findings concerning human addiction.

The comparisons made with results reported in the literature will be limited in general to a consideration of the effects reported in studies in which morphine was used, although it will be necessary occasionally to consider the relevant results secured by the use of other opiates, such as heroine, dilaudid, and codeine, as well as the other familiar addicting alkaloid, cocaine. Morphine is easily the most important of the alkaloids, however, from the standpoint of social as well as clinical significance, and the majority of the experimental investigations have used it in studying the effects of addicting drugs.

2. Terms and definitions

Because of the fact that the problems of drug addiction have been approached from so many different viewpoints and interests—physiological, pharmacological, behavioral, clinical, sociological—it is not surprising that a certain lack of agreement exists with reference to the terms employed, and that the same

word may signalize quite different concepts to different workers. Thus, for describing the state induced by the continued administration of morphine, we find in general use the following wide variety of terms: morphine addiction, morphinism, chronic morphinism, chronic morphine poisoning, morphine tolerance, morphine dependence, morphine habituation, craving, appetite, mania, and many others. There are certain writers who insist on definite distinctions between some of the above terms, but it is possible to cite instances in the literature in which each of the terms in the above list has at some time or other been used synonymously with any of the other terms.

Concerning the effects resulting from the cessation of continued administration there is considerably better agreement. Practically all investigators refer to them as abstinence phenomena or withdrawal phenomena.

Perhaps the most definitive statements regarding the use of terms are those which have been set forth by Tatum, Seevers, and Collins (1929) and Tatum and Seevers (1931). In these two papers, this group of workers has proposed the following definitions:

Addiction. That condition of mind or body induced through repeated drugging, such that the continued use of that drug becomes necessary, and cessation causes serious mental and physical derangement.

Habituation. A condition wherein one becomes accustomed to a drug, but not seriously dependent upon it, i.e., cessation produces no ill effects.

Tolerance. A phenomenon characterized by the fact that progressively larger quantities of a drug must be used to produce equivalent effects. (There may be tolerance without addiction, or vice versa, or both together.)

Their position has been stated with clearness in the following paragraphs:

Tolerance to some drugs develops without addiction. Without tolerance development, certain drugs can scarcely be considered to have established an addiction. On the other hand, addiction to certain other drugs is known to occur in which an increased susceptibility

actually occurs. Finally, tolerance may develop throughout one phase of the drug taking, to be replaced by a relatively increased sensitivity in a later phase.

True addiction, then, is a condition in which, through some process or other, the organism needs a repetition of the drug for its effects in order to approximate normality more nearly and, in the case of man, also to satisfy conscious desires or to escape painful sensations or painful thoughts. In the continued use of morphine there readily develops some degree of tolerance to the depressant action, and without this developed tolerance morphinism can scarcely be held to have occurred. The condition of tolerance could not be doubted if, on repetition, a dosage comes to be tolerated which would cause serious consequences or death in the non-addicted organism. (Tatum, Seevers, and Collins, 1929, pp. 466–467.)

It is evident that to these workers, "addiction" is synonymous with "dependence," and is to be distinguished from "tolerance" and "habituation." According to this viewpoint addiction to morphine has frequently been demonstrated in many of the lower animals as well as in man. The criterion is merely the demonstration of a dependence induced by repeated doses of the drug, so that cessation of doses produces objectively observable physiological disturbances. These writers do recognize that in human addicts there may be the additional factor that the drug is needed "to satisfy conscious desires or to escape painful sensations or painful thoughts," but it is apparent that for them this factor of positive desire and striving for the drug is not a fundamental part of addiction as an organic phenomenon. They hold that addiction is primarily "dependence," and the presence of addiction demonstrated when withdrawal symptoms appear.

A number of recent investigators have followed Tatum and his co-workers in their usage of the above terms, some explicitly and others more implicitly. However, one can point to several reports in which, for example, the term "habituation" has been used synonymously with "addiction" (Faust, 1900; DuMez, 1919; Hatcher and Gold, 1929), and some in which the term "tolerance" has been so used (Plant and Pierce, 1928; Schmidt and Livingston, 1933).

These definitions of terms as set forth by Tatum et al. have undoubtedly proved of value for the bulk of the animal experimentation that has been carried on in this field. Practically all the research on this topic which has employed animals as subjects has been pharmacological and physiological in its essential interests, and, naturally and conveniently, addiction was defined in terms of pharmacological effects on physiological functions. Demonstration of the appearance of these aberrant physiological functions constituted evidence of addiction in the animals used.

However, various investigators have long realized, more or less explicitly, that there is something more than simple physiological malfunction in the picture of the human morphine addict, i.e., something in addition to purely physiological dependence. But this factor has been almost entirely dismissed from consideration in the work with animals, because it was "subjective" and "not susceptible to objective techniques." And thus the word addiction has come to have a different meaning when applied to the animal subjects of chronic morphine experiments than it does when applied to the human chronic morphinist. In the latter case, it is generally recognized and agreed that the factors of positive desire and craving for the drug—the so-called subjective aspects of addiction—are of at least coördinate importance with the induced physiological dependence.

It would also be admitted by researchers in this field that, on withdrawal, the "addicted" animal is a disturbed and sick, but a *passively* sick animal, whereas the addicted human, on withdrawal, may be characterized not so much by his purely physiological disturbances (which may be essentially relatively mild), but by the intense craving which he exhibits for an injection of the drug. It is this powerful desire for the dose that typically dominates the picture of withdrawal in the human addict.

Because of these differences it seems unfortunate that the term "addiction" has been so commonly used to describe both the state of the chronically morphinized animal and that of the human addict. It is proposed in this study to limit the use of the term "addiction" to those instances, *either in man or in lower animals*, in which an actual *desire* or *striving* for the drug is clearly demon-

strated in addition to the induced physiological dependence. In those cases in which physiological dependence has been induced in animals by repeated doses of morphine (or other opiates), but in which the factor of positive desire for the drug has not been demonstrated, or has been shown to be not present, the term "addiction" will be avoided, and the terms "dependence" or "chronic morphinism" used instead to describe the resulting state.   In this way it is hoped to emphasize in the concept of addiction the motivational and psychopathological aspects of the state.

The term "tolerance" has been subjected to but little ambiguous use and seems to have a relatively unequivocal meaning in the literature, viz., the definition of Tatum et al. which was set forth above.   That usage will be followed here.   Likewise with regard to "abstinence phenomena" and "withdrawal phenomena," the meaning is clear and the agreement satisfactory; the terms refer to the syndrome of objective symptoms which result from the cessation of chronic administration of the drug.

3. Evidences concerning desire for the morphine injection

There are many reports of chronic morphinism experiments with animals in which no mention is made, either on the positive or the negative side, of any indications or inferences of the development of a desire for the drug on the part of the animal subjects.   It is true that these experiments were typically carried out in the attempt to secure evidence bearing on certain physiological effects of the drug, its pharmacological action and fate, but it is regrettable from the point of view of our present interest that there has been so often neglected in these experiments a report of the general behavioral effects of morphinism and observations on the possible appearance, or lack of appearance, of any behavior which might be interpreted as genuine addiction.

There have, fortunately, been a few papers in which the possibility of development of desire for the drug has been considered, among them some which devoted careful study to this topic. But even here there has been reported no attempt to test in any definite and unequivocal manner for the presence of desire for

the drug, and the evidence presented has been necessarily limited to general observations of behavior and clinical interpretations.

Faust (1900) induced chronic morphinism in dogs, and reported that after three to four weeks the animals became accustomed to the injection, "as if they felt the need of a new injection . . . indeed, in one case the dog would greet me with lively expressions of joy, when I entered the cage with syringe in hand, and let the injection be made while he is standing, without being bound in any way, or with his free movements hindered, apparently with a good deal of pleasurable delight" (pp. 229–230; condensed translation). In the absence of further evidence the student of animal behavior would certainly desire to know much more about the isolation and control of other factors in the situation (such as the relation of injection to feeding, etc., etc.) before he would be willing to accept this account as adequate evidence of desire for injection.

Plant and Pierce (1928) found that morphine caused marked dependence in their dogs, with many disturbances of function upon its withdrawal, which could be characterized mainly as a passive sickness. They state that: "While it is true that very few of our animals have a complete picture of the usual symptoms observed in human addicts after abrupt withdrawal, yet together they form a composite picture that includes practically all of the human symptoms that could be distinguished in an animal" (p. 354). One dog in particular showed symptoms which the authors stated to be very similar to those of abrupt withdrawal in human addicts. During withdrawal this dog, they state, "seems actually to beg for a dose" (p. 355); she became quiet when placed on the table for injection, and was friendly and normal within a few minutes after injection. Although these writers assert that the picture in their dogs includes *practically all* of the human symptoms that *could be* distinguished in an animal, their evidences of behavioral effects of morphinism and of withdrawal are based on general observations and there were no tests made to determine objectively whether the animals would exhibit striving for the drug. The quieting, etc., in the injection situation might very well be explained as a conditioned response

to the situation which uniformly produced quietness and sedation in the past.

Barbour, Hunter, and Richey (1929), in a study of water metabolism during morphinism and morphine withdrawal, found that their dogs became restless during withdrawal but developed few other symptoms. They state that "only one or two dogs showed apparent craving" (p. 260), but do not amplify this statement in any way, so as to indicate what the behavior may have been which gave rise to this inference.

Hatcher and Gold (1929), as a result of their experiments with chronically morphinized dogs, state, "We did not observe anything that we interpreted as a manifestation of a desire on the part of the dog for the morphine" (p. 266). Some of their dogs coöperated in the injection procedure, but "this was interpreted as the training of an intelligent animal" (p. 266).

Tatum, Seevers, and Collins (1929) carried out acute and chronic morphinism experiments with dogs, rabbits, cats, and monkeys. Of their dogs they state that withdrawal of the drug caused nervousness, tremors, etc., but, to quote them: "We have not seen any clear convincing evidence of desire for the drug on the part of the dog. They will submit but do so without signs of intense desire as is positively developed in chronic cocainism, as described by us elsewhere" (p. 452).[1]

Their rabbits failed to develop tolerance to morphine and often died after a few weeks of steady daily dosage; thus the addiction possibilities seem very slight. "In our series of cats . . . we have seen submission but no evidence of desire for the drug. On the

[1] Tatum and Seevers (1929) have reported some experiments on the chronic administration of cocaine to monkeys and dogs. They found that their animals developed no tolerance to the drug, nor did any abstinence symptoms appear on withdrawal. Such results, of course, contrast markedly with the effects produced by chronic administration of opiates (morphine, heroine, codeine, etc.) to animals and humans.

They present evidence from observations of the general behavior of their dogs which indicates the appearance of a desire for the cocaine injections. Their monkeys, however, did not exhibit such behavior; in fact, they consistently exhibited aversion to the injections. No reasons are advanced to account for this discrepancy between the reactions of dogs and monkeys to daily injections of cocaine.

contrary, they develop a well marked conditioned salivary reflex which we interpret as a sign of aversion" (p. 456). Chronic administration of morphine to several monkeys caused the writers to observe that, "At no time do the animals evince any sign of wanting the drug; in fact, they struggle and fight against it, and show as much resistance to injection as is seen at the beginning" (p. 460). They attempt to explain this by saying: "The absence of evident desire for the drug, in spite of the need in the case of the monkey, may be due to the fact that these animals do not accept handling as kindly as do dogs. Thus, the dislike of being handled may mask or prevent the manifestations of conscious desire" (p. 461).

It is evident that nothing was observed in the morphine experiments of these writers that could be interpreted as signs of addiction, i.e., of desire for the dose. With regard to their suggestion that the absence of positive desire in the monkey may have been due to aversion to handling, it must be granted that this factor remains as a possibility, even though it may seem rather difficult to believe that if these animals really had developed a complete, human-like addiction to the drug, the desire for the drug would be completely masked by aversion to handling. Available evidence from human cases indicates that when a genuine addiction is present, the organism's need for the drug during a withdrawal period is by far the most predominant motivating factor present, and takes precedence over practically all other needs and impulses. Continuous resistance to injection throughout the course of the experiment would seem to indicate that addiction did not appear or, at most, was but feebly developed.

Kolb and DuMez (1931) performed chronic and acute experiments on monkeys, using morphine, codeine, and heroine. Marked dependence was induced by morphine, as shown by the appearance of withdrawal symptoms on cessation of doses, but their animals on withdrawal were *passively* sick animals. No mention is made of any evidence of desire for, or solicitation of, the drug.

Seevers (1936a) attempted to provide conditions which would

favor the chances of his animals associating the injection of the drug with subsequent relief from the distressing symptoms of abstinence. In order to achieve this condition, he argues, it is necessary that the relief of the symptoms occur very quickly after injection—within two or three minutes. For this reason he rejected morphine and dilaudid (as he states that they do not bring relief from withdrawal distress for ten or fifteen minutes) and chose heroine (which, he asserts, is less painful on injection and brings definite relief within three to five minutes).

Thirty-four rhesus monkeys were used in this study, from periods of four months to two years, and extended observations of "addiction" and withdrawal carried out. Concerning the appearances of desire for the drug, Seevers states:

Animals addicted to heroine actually behave as if they desire the drug, particularly during a prolonged withdrawal. One animal, addicted for fifteen months, would sit on the table, or lie quietly on her back without restraint, to receive the injection of 6 cc. of 1 per cent heroinehydrachloride without wincing, and would chatter and call throughout the procedure. No especial effort has been made to tame this animal who originally was the wildest of the group. Others will follow the attendant about in the pen, clutching at his clothing, and will return time and time again even though repelled. It may be argued, of course, that peaceful submission to the injection is fundamentally different from the establishment of a positive desire for the drug. In the final analysis, however, it should be agreed that the former is a preliminary step in the achievement of such a response. It is a common observation that all of the animals are more docile and easily handled during the height of abstinence from other addicting opiates. This occurs at the forty-eight to seventy-two-hour period, and may result from the fact that they are so exhausted that they do not feel like offering resistance. It has been suggested, that, if the drugs were injected intravenously, where a minimum of pain and rapid onset of action are obtained, the necessary association could be more easily established. (Pp. 148–149.)

It is on the basis of this evidence that in his summary (p. 155) Seevers interprets the behavior to be "the establishment of a positive desire for the drug during abstinence." No evidences

for addiction are reported in this study other than the statements quoted above. The behavior of the one animal which he describes, presumably selected as the best example from among the group of 34 animals, certainly indicates a considerable amount of coöperation in the injection situation. But is there anything in the above-quoted description which establishes that the behavior was evidence of addiction and not purely coöperation (or lack of resistance)? We believe not, and the author grants in the same passage the cogency of the argument that peaceful submission to the injection may be fundamentally different from the establishment of a positive desire for the drug, while maintaining that such submission is a preliminary step in the achievement of such a response (addiction). The "clutching at clothing" and "following about the pen" would, of course, need the isolation and variation of many environmental factors before such behavior could be accepted as convincing evidence of desire for injection.

This is not to deny the possibility that Seever's monkeys *may* have developed a positive desire for the heroine injections, but to state that his report does not contain adequate evidence of the definite, unequivocal appearance of such desire. The behavior which he reports may be interpreted without reference to the factor of genuine addiction.

In another study Seevers (1936b) has reported further experiments with monkeys, comparing the effects of dilaudid with morphine, heroine, and codeine. Heroine and morphine were found to give the most severe abstinence symptoms, those of dilaudid were considerably less, whereas with codeine the convulsant action of the drug prevented the attainment of comparable doses. No mention is made in this study of any evidence of induced desire on the part of the monkeys for any of the drugs used.

This account summarizes the evidence which the writer has been able to locate relative to the question whether animal subjects exhibit a desire for morphine injections. In the light of the experiments cited the following statements seem to be warranted:

1. For most of the lower animals there are no dissenting findings to the generalization that evidence of desire for the drug has never been exhibited.

2. For the dog and the monkey the weight of experimental evidence is heavily on the side of the assertion that these two animal forms likewise do not exhibit any desire for morphine injections.

3. In those cases in which animal behavior has been described which the writers have asserted to be indicative of such desire, this behavior has never been experimentally isolated and tested, but has been described only in terms of general and incidental observations of behavior. The possibility of errors of observation and interpretation is considerable.

The writer feels justified in concluding, therefore, that up to the present time morphine addiction (in the sense in which he has proposed to limit the term) has not been demonstrated in any infrahuman organism.

B. STATEMENT OF THE PROBLEM

Because of the conflicting and inconclusive experimental results that had thus far been brought to bear on the problem, and in view of the theoretical as well as practical importance of determining whether or not an infrahuman organism can develop a genuine addiction to morphine, it seemed well worth while to attempt a morphinism study in which factors should deliberately be made as favorable as possible for the creation of addiction. This implied not only carefully planned experimental procedures, but also the selection of an animal as subject which would seem *a priori* to offer the greatest probability of securing positive results in such an investigation. The value of a given animal type as research material for a study of this kind obviously depends to an important extent upon the degree to which its reactions to drug administration and deprivation correspond to those which appear in man.

Numerous observational and experimental studies of anthropoid apes, several of which have been carried out in these laboratories, have well established that many of the functional char-

acteristics of the chimpanzee resemble corresponding human functions more closely than do those of any other infrahuman species. This affinity suggested the possibility that the chimpanzee might be peculiarly useful as subject in the study of certain basic problems on the nature of drug addiction.

With these several factors in mind a project was initiated (under the direction of Professor Robert M. Yerkes, at the Southern Division of the Yale Laboratories of Primate Biology), seeking answers to the following questions: (1) What are the effects of repeated doses of morphine on chimpanzees? (2) Is there evidence that this animal, like man, can develop a genuine addiction to the drug? (3) If so, how similar are chimpanzee and human addiction? (4) Do the results indicate whether chimpanzees (and possibly other primates as well) might possess peculiar value as a substitute for other test animals, and even for man, in certain kinds of investigation of the effects of narcotic drugs?

This project was, in brief, an exploratory attempt to determine as much about the nature of chronic morphinism in chimpanzees as could be done with the subjects and facilities available, the primary purpose being that of attempting to determine whether or not the chronically morphinized chimpanzee would exhibit an addiction to the drug.

The investigation was approached, first of all, with the conviction that in very few, if any, of the animal experiments on the nature of chronic morphinism have conditions been optimal from the point of view of permitting the appearance of any desire for the morphine injection which might otherwise have developed. Most of these investigations have been carried out by workers whose interests lay, justifiably, in the physiological and pharmacological, rather than the behavioral effects of the drug. It is not surprising then that many of the procedures did not provide optimal opportunities for validly demonstrating addiction. For example, to catch and inject as timid an animal as a monkey *by force*, day after day, is a procedure which might well produce a strong, stable habit of struggle and avoidance whenever the animal is confronted with the injection situation. When, added

to this, we have the fact that the effect or "reward" of a morphine injection does not become manifest for some ten or fifteen minutes, it is easily understandable how such struggle reactions might persist, even though the monkey has become physiologically highly *dependent* on the drug.

A second consideration which has dominated our approach to this problem has been the realization that if evidences of addiction should appear in the chimpanzee, such evidences must be clearly and unequivocally demonstrated by an objective experimental procedure, so that the conclusions, to that extent at least, will be independent of the experimenter's interpretations based on observations of general behavior.   This is not to assert that observations of general behavior should be relegated to a place of minor importance in this study; on the contrary the writer believes that they form a very important part of the total body of data.   It is maintained, however, that the primary evidence of addiction will have to be stated in terms of results secured in an objective test situation, one which has been designed specifically to test the presence or absence of a desire for morphine on the part of the animal being studied.   On the basis of such test results one should be in a position to state definitely whether or not his animal subjects really became addicted to the narcotic drug.

PART II. EXPERIMENTAL

A. THE ADMINISTRATION OF SMALL, ISOLATED DOSES OF MORPHINE TO NON-TOLERANT CHIMPANZEES

Preliminary to a description of chronic morphinism in the chimpanzee we present some observations on the effects of small, isolated doses of morphine on chimpanzees that were not tolerant to the effects of the drug.   These observations, covering a period slightly less than two years, were made in the course of administering sedative doses of morphine to several young animals in the laboratory colony, for the practical purpose of rendering them quiet and tractable for medication, bodily measurement and examination, and other manipulations which could not easily be accomplished otherwise.

The data thus accumulated total 35 cases, from 15 different animals (ranging in age from 2 to 7 or 8 years), and include the initial doses for each of the four animals that served as subjects in the morphinism experiments.   Doses ranged from 0.1 milligram (of the salt) per kilogram of body weight to 4.0 mg. per kg.   For these injections the untrained animal was usually held supine on a table by two or more attendants and the injection made subcutaneously over the abdomen.   (A more complete description of the drug and the solution employed, as well as the regular method of injection used in the morphinism experiments, will be given later.)   The cases are distributed with respect to dose size as follows:

Dose size, mg. per kg.	Number of cases
0.1 to 0.9	6
1.0 to 1.9	3
2.0 to 2.9	12
3.0 to 3.9	10
4.0	4
Total	35

Doses of 0.1 to 0.9 mg. per kg. produced no observable sedative effect and little if any pupillary dilatation.   At the injection site

there characteristically appeared a small wheal and the animal usually scratched at it within 2 or 3 minutes after the injection had been made. The most noticeable effect of doses in this range was the large amount of generalized scratching (accompanied sometimes by hair-plucking and grooming behavior with the characteristic lip-smacking noises) that appeared 10 to 15 minutes after injection and persisted for an hour or more. The drug seemed to produce a cutaneous hyperesthesia. The animals did not seem to be distressed by it; they seemed rather to be interestedly engrossed in the scratching and skin examination. No gastro-intestinal effects were observed, no changes in salivary rate, nor diminution of appetite.

Doses of 1.0 to 2.9 mg. per kg. (most of which were 2.0 mg. per kg.) produced a definite sedation. Within 10 to 15 minutes the animal began to appear drowsy and sluggish and somewhat incoördinated in its movements, to spend most of its time sitting quietly against the cage wall or wedged into a corner, alternated with periods of restless pacing about the cage. During the quiet periods the eyelids would often droop and fall closed, and the head and trunk would progressively relax. The animal would usually rouse itself before dozing off and be active for a short time. This process would repeat itself, the animal appearing to fight against the drowsiness whenever it threatened to become overpowering. Pupils were regularly dilated, with irregular fluctuations in size which appeared to be independent of changes in external illumination.

Sedation lasted for 4 to 6 hours usually; during this period the animal was passive and relaxed and would permit itself to be manipulated in ways which ordinarily would be vigorously resisted. Mingled with the drowsiness were signs of excitement. If the observer sat quietly watching an animal during this period, then spoke to it or moved about the cage, such stimulation often induced brief crying, or excited hooting and calling; if the observer then remained quiet, the animal would again become silent and drowsy. Picking the animal up usually induced a few struggle responses and some crying, but once the animal had been secured it became passive and quiet in the observer's arms.

The scratching and picking, which was described above, was

considerably increased for doses in this range. Some of the animals scratched so vigorously that the skin was reddened for a day or so afterward. The scratching tended to be most frequent from 10 to 20 minutes after the injection and again 4 to 5 hours later. It was diminished during the period of sedation.

Appetite was reduced for 6 to 8 hours; the animals would usually eat slowly when food was presented to them, but would leave a considerable part of their regular ration untouched. By the next morning, however, appetite as well as activity would be entirely normal.

Feces became firmer for 24 to 48 hours, but no constipation was observed. Neither emesis nor defecation occurred as a result of the injection, in contrast to its frequent appearance in dogs.

Larger doses, 3.0 to 4.0 mg. per kg. in size, did not produce noticeably greater effects than did doses of 2.0 mg. per kg. On the basis of these limited data, there seems to be an "indifference region" from 2 to 4 mg. per kg. for these animals. Our data do not go beyond 4 mg. per kg. The larger doses produced effects which were similar in all essential respects to those described above for smaller doses, with perhaps somewhat greater persistence of effects. Even this is not clear, however, as some of the cases with smaller doses showed as much or more sedation than other cases with a dose of 4 mg. per kg. Individual differences in reaction to the drug seem to be more important here than the difference in sizes of dose which were used.

The observations reported in this section provided us with knowledge of the reactions of young chimpanzees to small, isolated doses of morphine. On the practical side they demonstrated the usefulness of this drug as a means of rendering the animals passive and tractable for various manipulations and examinations.

B. CHRONIC MORPHINISM IN CHIMPANZEES

1. Subjects

Four young chimpanzees, three males and one female, of the Orange Park colony of the Yale Laboratories of Primate Biology, served as subjects for the chronic morphinism experiments.

Each had been used extensively in the New Haven laboratories for several years in various behavioral experiments, and had been transferred to Orange Park a few weeks to a few months prior to their use in the morphine investigation. A brief description of each animal follows:

Velt (no. 31 in the laboratory records). Male. Hypothetical birth date: July, 1929. Sexually mature (live sperm found) but not full-grown at the beginning of the experiment. A rather reserved, cautious animal, not very active. Had been ill, presumably from a parasitic infestation, several months before injections were started, but recovered satisfactorily. Injections begun during March, 1936, and continued for 13 months. Was $6\frac{3}{4}$ years old at the beginning of the experiment.

Lyn (no. 27). Male. Hypothetical birth date: November, 1929. A sexually immature, adolescent animal; lively, friendly, and in excellent health. Injections begun during March, 1936 (at which time he was a little less than $6\frac{1}{2}$ years old), and continued for 7 months.

Kambi (no. 24). Female. Hypothetical birth date: June, 1929. An adolescent, sexually immature animal, quiet and rather stolid; in good health. Several periods of sexual skin swelling had been observed prior to use in this experiment, but menstrual bleeding had not yet occurred. Injections begun during March, 1937 (when she was $7\frac{3}{4}$ years old), and continued for 4 months.

Frank (no. 25). Male. Hypothetical birth date: January, 1930. Sexually mature (live sperm found) but not full-grown at the beginning of the experiment. In excellent health; a lively, friendly animal. Injections begun during June, 1937 (when he was $7\frac{1}{2}$ years old) and continued for 6 weeks.

2. "Pre-morphine" tests and measurements

Prior to administration of morphine the animals were given an extensive series of tests and measurements, behavioral and physiological, to serve as a base-line against which to compare their performances during states of morphinism and withdrawal: physiological—metabolic rate, nocturnal activity records, blood counts, rectal temperature, pulse and respiration rate, body weight, and observations of general health and activity; behavioral—training on platform and stick problems, box-stacking problems, a delayed-response problem with varying intervals of

delay, a multiple-choice problem, and controlled observation of social and sexual behavior. Data from these tests and measurements will be presented later in connection with observations made during periods of drug administration and withdrawal.

3. Administration of the drug

The drug, morphine sulfate pentahydrate, was supplied for this investigation by the United States Public Health Service. It was produced by Doctor Lyndon F. Small at the Cobb Chemical Laboratory of the University of Virginia and, according to Doctor Small, contained 73.1% of the alkaline base. A 5% solution of the drug was used, made up 100 cc. at a time as needed. Each cc. of solution thus contained 50 mg. of morphine (36.55 mg. of the alkaline base).

Prior to receiving morphine injections, all subjects were trained to coöperate voluntarily in receiving hypodermic injections of physiological saline solution. The procedure was as follows: The hair was clipped short over the scapular region, where the skin is loose. Then the animal was trained to lean across the experimenter's leg, when he placed his foot up on the bench (see figure 1). With this injection position the experimenter had good control of the animal and—an important factor—was working on an area out of the animal's sight. Training proceeded by having the animal assume this position, scratching him lightly in the scapular region with an ordinary needle, then rewarding him with a piece of fruit. After a little experience the animals came to tolerate the scratching and pricking, even when quite vigorous, in order to obtain the fruit reward. The hypodermic needle was then substituted for the ordinary needle, and actual injections of small amounts of saline solution were made. Fruit, praise, and patting followed the injection. The animals were then trained to the point where they readily coöperated for injection with only verbal approbation as reward (or none at all), before morphine injections were given. The morphine injections were not followed by food reward.

It is the writer's contention that this preliminary adaptation to the injection situation was an important factor in the experi-

ment; it obviated many undesirable aspects which would have appeared if it had been necessary to inject the animals by force. In fact it may very seriously be doubted whether the experiment could have been carried on at all with these chimpanzee subjects (weighing from 25 to 32 kilograms) if it had been necessary to attempt to hold them forcibly for daily injections. As a result of the preliminary training, however, the daily injections soon became as routine a matter as being put on leash, weighed, etc.

Lyn and Velt were started with very small doses, 0.1 mg. per kg., once a day. The dose was increased slowly until 8 weeks later these two animals were getting 2 mg. per kg., twice daily; it was maintained at this level for some 6 months. Then, for Velt, it was increased to 3 and later to 4 mg. per kg., twice daily, and kept at that level until shortly before his death.

Frank was also started on very small doses, 0.1 mg. per kg., but in his case the dose size was increased relatively rapidly. Two weeks after the beginning of injections he was getting 2 mg. per kg. of the drug, twice daily. He was kept at this dose level until the end of the experiment.

Kambi's daily injections were begun with doses of 2 mg. per kg., a dose size that had been shown to be definitely sedative for chimpanzees (see above), in contrast to the non-sedative initial doses of the other three subjects. Her daily dose was soon split into two parts, then gradually increased so that after 7 weeks she was getting 3 mg. per kg. of the drug, twice a day. The dosage was maintained at approximately this level until the end of the experiment.

In this manner, with two cases of gradual increase in size from initially very small doses, one case of relatively rapid increase from small dose size, and one case which was begun with doses of sedative size, it was hoped, despite the small number of subjects used, that some light might be thrown on the rate of onset of dependence and addiction as a function of dose size and rate of increase.

With but few exceptions injections were administered twice daily; shortly after 9 a.m. and shortly before 5 p.m. On Sundays a single dose was given about 11 a.m. Thus an interval of

7 to 8 hours elapsed between the morning and the afternoon injection, and 16 to 17 hours between the afternoon injection and that of the following morning. Since the depressant effects of morphine wear off in 6 to 8 hours, and in view of the relatively small amount of nocturnal activity in chimpanzees, this schedule of drug administration represents a fairly adequate balancing and spacing of doses. For most rapid onset of addiction there is evidence to show that injections every 6 hours without fail would be optimum, but obviously such a schedule would hardly be feasible in an experiment of this kind. It is well known that complete addiction in human beings can easily be established on two, or even on one dose a day. Probably there are many addicts who stabilize themselves on two doses a day, one shortly after rising in the morning, and the other in the late afternoon or early evening. Thus our drug administration regimen, while not optimal from the standpoint of inducing most rapid dependence, approximates the regimen found in human cases more closely than does a so-called "ideal interval" dose.

From time to time periods of abstinence from the drug were introduced, most of which were from 40 to 48 hours' duration. Light (1929) and others have shown that in man abstinence symptoms reach their maximum severity by that time, and that relatively little tolerance to the drug has been lost. If longer withdrawal periods are used, little, if anything, further appears in the abstinence syndrome. On the other hand, tolerance is rapidly lost after the 48-hour point, and the resuming doses have to be made very small in order to avoid dangerously toxic effects.

The withdrawal periods facilitated observation of the appearance and increase of dependence on the drug, the nature of the abstinence syndrome, and any indications of appearance of desire for the morphine injection. A detailed account of the withdrawal periods will be presented later.

4. Early effects of the morphine injections

a. On physiological functions. With most warm-blooded animals the effect of morphine doses is to produce sedation and, even with long continued administration of the drug, there is

FIG. 1

FIG. 2

FIG. 1, upper. The voluntary coöperation of a subject (Velt) for hypodermic injection. The same position was employed for the taking of rectal temperature.

FIG. 2, lower. Skin lesions made by scratching, as a result of the morphine injections (Kambi). Note the many raw spots on legs, arms, and head. Others on abdomen and chest are not apparent in this picture.

27

evidence that tolerance to the sedative effect never becomes complete (Plant and Pierce, 1928; Hatcher and Gold, 1929; and Himmelsbach, Gerlach, and Stanton, 1935). Several investigators have shown that in the cat the effects of morphine are predominantly stimulating, but in almost all other animals a definite tolerance to the sedative effect is developed. During withdrawal morphinized animals are restless, irritable, and hypersensitive (Plant and Pierce, 1928; Tatum, Seevers, and Collins, 1929; Kolb and DuMez, 1931; and Seevers, 1936a).

No observable sedation resulted from any of the morphine injections given to Lyn, Velt, or Frank. They were started on doses so small and the dosage increased so gradually that they did not exhibit any indications of a sedative reaction to the drug at any time during the experiment. Kambi, who was started with doses of 2 mg. per kg., did at first exhibit sedation from the daily doses. She would appear drowsy and sluggish for several hours after injection. Within 7 days this effect had noticeably diminished, however, and after 4 or 5 days more no sedative effect of the drug could be observed.

The most prominent effect of the early daily doses of morphine was the appearance of a great deal of scratching, picking at hair and loose bits of skin, scabs, etc., as well as hair-plucking. All four subjects regularly began scratching and picking within 10 minutes after injection, and this reaction persisted throughout the experiment (13 months in the case of Velt) with but little diminution. Scratching was so vigorous that many skin lesions were made, especially by Kambi and Velt, who would keep the spots raw by picking the scabs off them almost as fast as they were formed. Figure 2 shows several of Kambi's skin lesions in a picture taken less than 2 weeks after she had begun receiving daily injections of morphine. The limbs, head, and abdomen were the areas most frequently attacked.

Hair-pulling was a regular effect of the doses, and was carried to excess by Frank and Velt, who almost denuded themselves. This is strikingly shown in figures 3 and 4, in which Frank is portrayed just before injections were begun and again 4 weeks later.

Fig. 3

Fig. 4

Fig. 3, upper. Frank, taken a few days before daily injections of morphine were begun. Compare with figure 4.
Fig. 4, lower. Frank, taken 4 weeks after daily injections of morphine had been begun. Note scars and scabs on limbs and head, as well as the almost complete denudation.

That both hair-pulling and scratching were clearly due to the morphine was shown by several controlled observation periods in which the amount of such activities was compared, following injections of saline solution and following morphine injections. The results left no doubt that morphine was the responsible factor.

Itching, especially about the face, has frequently been reported for man following sedative doses of morphine, but, to the best of the writer's knowledge, never to the excessive amount that the behavior reported here would indicate. Whether these animals actually received more cutaneous stimulation from the drug than man does, or whether they were merely less inhibited about scratching and picking, is a question which these observations do not settle; it may well be that both factors were important.

Together with the picking, scratching, and hair-plucking, there often occurred the lip-smacking noises of engrossed attention that characterize grooming behavior in the chimpanzee (see Yerkes, 1933). There was also, after injection, an increased tendency to groom the experimenter's hands, shoes, buttons of coat, etc. This was especially noticeable in Kambi and Frank, less so in Lyn and Velt. Morphine seems to lower the threshold of the mechanism, whatever it is, that sets off grooming behavior in the chimpanzee.

The effects of the doses on specific bodily functions are described below, in comparison with results which have been reported in other animal experiments.

(1) Body weight; appetite; elimination. Most investigators report that their animals lose weight during chronic morphinism experiments. Plant and Pierce (1928) found that for a few weeks after injections were started their dogs lost weight rather rapidly, then recovered or remained at a relatively constant weight for the duration of the experiment. Some weight gains late in the experiment were reported. For the monkey, Seevers (1936a) found that the majority of his animals lost weight during a long period of drug administration, and that this was to some extent secondary to appetite reduction, but not wholly. Growth and maturation were retarded by the drug.

In the present experiment, the initiation of daily injections

caused a weight loss which persisted as long as 6 weeks, after which time the animals maintained their weight or slowly gained. Figure 5 describes the effect of the first few weeks of morphine injections on the body weights of the four subjects. It is seen that Frank, Kambi, and Lyn immediately began to lose weight
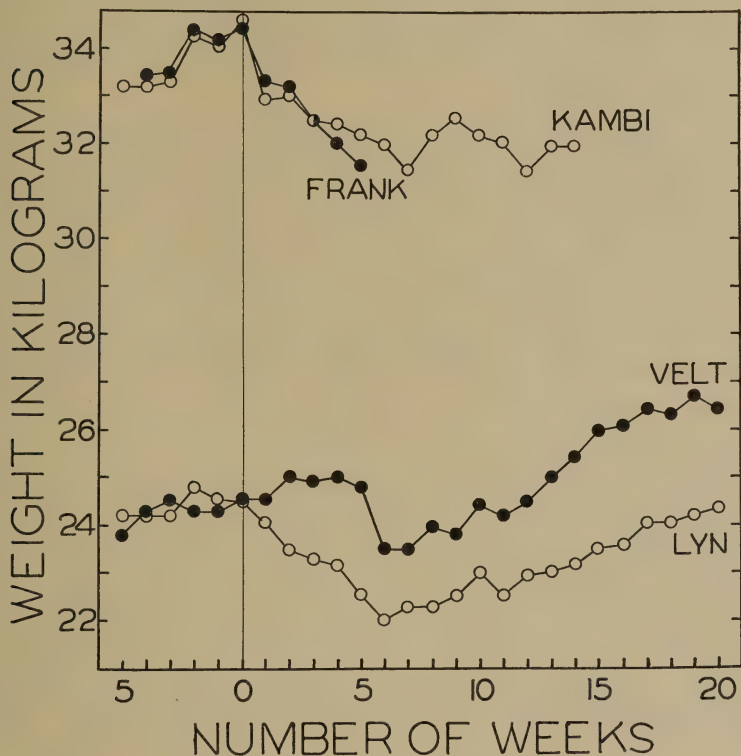
Fig. 5. Changes in body weight following daily injections of morphine. On the abscissa are shown the 5 weeks preceding the first morphine injection (which is the "0" point), and the first 20 weeks of morphinism. Curves for Frank and Kambi end earlier than those for Lyn and Velt, due to their briefer morphine experience.

when morphine injections were started. Velt, who was recovering from the effects of a gastric disturbance and gaining weight rapidly when injections were started, continued to gain slowly for a few weeks, then lost weight when the dose was increased and dependence appeared.

The graphs of weight changes indicate that the animals soon

reached a new equilibrium and, after attaining it, their physiological processes were functioning with an efficiency not much less than before injections were begun; certainly they function more efficiently than during the first 2 or 3 days of a prolonged withdrawal period. Increases in body weight were not as rapid as they are for normal chimpanzees of this age (as shown by the norms presented by Spence and Yerkes, 1937), thus indicating that the drug exerts some retarding effect on the physiological processes of growth.

Appetite was diminished for several days following the beginning of daily morphine doses, then gradually returned to normal. The diminution was only slight for Velt, but was considerable for Lyn and Kambi. Lyn, Frank, and Kambi came to display less eagerness to take the milk and gruel mixture which was given each afternoon, but Velt remained eager for it. Certain vegetables declined in favor during the experiment, but fruits, especially oranges and grape-fruit, remained high in preference value. Appetite for the morning meal was definitely better after injection than before.

Gastro-intestinal effects have been conspicuous in many of the descriptions of morphinism; they appear to be among the most striking effects of the drug. In his pioneer work Bernard (1864) described retching, vomiting, and defecation in his dogs, following small doses of morphine. Faust (1900) reported that his dogs vomited as a result of morphine injections for the first 6 to 9 days. A number of other investigators have corroborated these findings in dogs, among them Collins and Tatum (1925), Kleitman and Crisler (1927), Plant and Pierce (1928), and Tatum, Seevers, and Collins (1929). Profuse salivation after doses also seems to be common in dogs.

In several instances these effects have become conditioned to the injection situation (injection room, sight of syringe, etc.). Conditioned salivation and vomiting have been reported by Collins and Tatum (1925), Kleitman and Crisler (1927), Plant and Pierce (1928), Crisler (1928 and 1936), Tatum, Seevers, and Collins (1929), and Krylov (1930).

Tatum, Seevers, and Collins (1929) did not find any vomiting or salivation from morphine doses in monkeys, however, and

Seevers (1936a) has reported that his monkeys never vomited and but rarely salivated after morphine doses, although one of his animals did develop a vomiting reaction to the sight of the attendant with syringe, and one developed a conditioned salivary reflex somewhat like that seen in dogs.

Plant and Miller (1926) found a decrease in the muscular tone of the stomach wall in dogs following morphine doses, with an accompanying decrease in frequency and amplitude of the peristaltic waves, even to the point of disappearance of the waves for several hours after a dose. Ellinger and Seeger (1934) found decreased gastric secretion in morphinized dogs. Miller and Plant (1926) have reported that injections of morphine produced an increase in the tone of the intestine, as well as an increase in the frequency and amplitude of its contractions. No tolerance was developed to this stimulating effect of morphine on intestinal contractions. Kreuger's (1934) results corroborated these findings.

In line with the effects reported on intestinal functions, many studies have mentioned the constipation resulting from morphine administration; it seems to be one of the most regular effects of the drug. Morphine-induced constipation has been observed in dogs by Plant and Pierce (1928), in dogs and monkeys by Tatum, Seevers, and Collins (1929), and in monkeys by Kolb and DuMez (1931), although Seevers (1936a) has reported that his monkeys did not exhibit constipation during heroine administration. In man constipation from doses of morphine is common clinical experience, while the habitual constipation of the morphine addict is almost without exception.

In the present experiment the daily injections of morphine never produced retching, vomiting, defecation, or any other observable gastric disturbance. The feces did become noticeably firmer when the injection routine was started, but no constipation due to morphine was observed, except for Frank in whom the injections caused a cessation of defecations for the first 48 hours. Throughout the experiment the drug continued to make the stool firmer than it would otherwise have been, but the amount and frequency of defecation were not noticeably altered.

(2) Body temperature. Helfrich (1935) has reported that

doses of morphine sulfate cause a rise in temperature in cats and guinea pigs and, to a lesser extent, in dogs, mice, and rabbits. Pierce and Plant (1928) found that the hyperglycemia which morphine injection produced in their dogs was accompanied by a fall in temperature. Hyperglycemia and temperature fall were also present, but less marked, during withdrawal. Kolb and DuMez (1931) found that their monkeys suffered a considerable drop in body temperature during withdrawal from morphine.

The subjects of the present experiment were trained to submit to the taking of rectal temperatures, using the same position that the animal had been trained to assume for hypodermic injections (see figure 1). Clinical rectal thermometers with known correction factors were used.

Body temperature is a difficult measure to make satisfactorily in the chimpanzee. Several considerations make rectal temperature a more satisfactory measure than oral or axillary temperature, yet even it is not free from important sources of error. The rectum of the chimpanzee is not well protected by gluteal structures from external temperature changes, as is the case in man or the dog; it may be considerably chilled by the animal's sitting on a cold or wet cage floor. One can guard against these hazards, however, and can obtain fairly satisfactory temperature comparisons between different conditions in the same animal.

Prior to administration of morphine, temperature records were taken on each subject three times daily for 7 or more consecutive days, in order to furnish a basis for comparison with later measures. Temperature measurements were then made three or more times daily during the first few days of morphine injections, and at other selected periods during the first 2 months, as well as later during the withdrawal periods.

Individual differences in rectal temperature were considerable, so that, considering the small number of subjects, an averaging of the results would seem a dubious procedure. Since a detailed presentation of results would involve far more space here than its importance warrants, only a summary of the findings will be attempted.

The first morphine doses produced a noticeable decrease in

temperature in Lyn, Velt, and Kambi, the last-named animal showing a drop in temperature of some 2°C. after the first two morphine doses. Frank, however, showed only a very slight temperature drop on the first day, and none thereafter.

Later measurements showed that within 6 to 10 weeks Lyn, Velt, and Kambi were exhibiting little or no temperature effects from the daily doses. Their temperature-regulating mechanisms had evidently become adapted to the regularly recurring presence of the drug. Most of the adaptation took place during the first 2 weeks but it was not complete for 6 weeks or more.

It can be stated then that for chimpanzees the probability is that small doses of morphine will lower body temperature, as measured rectally, but that continued doses will gradually lose this power.

(3) Pulse. Most investigators agree in reporting that morphine slows the heart rate: McCrea and Meek (1926), Rentz (1927), Tatum, Seevers, and Collins (1929), and others. Anderson (1929) asserts, however, that in man he found that morphine increased the pulse rate. (See Sollman, 1936, for a summary of the effects on circulation of different sized doses.)

Detailed records of pulse rate were kept for two subjects, Kambi and Frank, for several days just prior to morphine administration, during the first few days of injections, and at occasional subsequent periods. It was taken with the animal in a sitting position, quiet and relaxed; enough time was allowed to elapse before making the measurement so that the effects of walking to the observation room would not produce a spuriously high value. The rate was determined by palpation of the femoral artery, on the upper part of the inner surface of the thigh.

In Kambi the first injections produced a marked decrease in pulse rate; the drop was from 110 to 60 per minute in the first case, and from 112 to 64 per minute in the second case. As daily injections proceeded there was a marked decrease in the depression effect, especially in the afternoon records. Kambi was clearly becoming adapted to this effect of the drug, and by the end of the second week adaptation was almost complete.

In Frank very little depression of pulse rate was observed, even

from the initial doses, and adaptation was rapid. It should be recalled here that Frank was started on small, non-sedative doses, while Kambi was started with a dosage of 2 mg. per kg., a definitely sedative size. There is considerable evidence, from other animal studies as well as studies of human addiction, that tolerance to the depressant effects of morphine is acquired most rapidly by spaced doses, and by increasing the dose size from initially small doses, rather than starting with doses of sedative size.

For both Kambi and Frank a temporary depressant effect on pulse rate was noted whenever the dosage was increased to a new level, but the effect was apparent for only a day or so in most cases.

Pulse records for Velt and Lyn, the first two subjects used in this investigation, are not nearly as complete as for the other two subjects. They, like Frank, were started with very small initial doses, which were increased gradually; like Frank's, their results show little or no depressant effect of the drug on pulse rate.

The small number of cases and the individual differences found make any conclusions with respect to pulse rate merely suggestive. However, the depression that was found and the recovery from it as doses were continued, are clearly in line with what is known of these effects in human addicts and in other experimental work with animals.

(4) Respiration. Morphine doses have been reported to diminish the respiration rate of animal subjects: Maloney and Tatum (1930), Barlow (1933), and Stanton (1936). The same effect has been noted in man by Anderson (1929), Sollman (1936) and others. Plant and Pierce (1928) report that during withdrawal dogs exhibit panting and other signs of air hunger.

Detailed records of respiration rate were secured for two subjects, Kambi and Frank, at the same time that pulse rates were taken, and with the animals in the same quiescent, sitting position. The rate was determined by visual inspection of the animal's trunk and stop-watch timing. Measurements were made three times daily for a week prior to the beginning of morphine injections, for the first week of daily injections, and at several subsequent intervals.

For Kambi the first two or three injections of morphine produced an increase in respiration rate, somewhat greater than the regular increase from morning to afternoon measurements found prior to morphine administration. Subsequent injections produced no observable effect on respiration rate.

For Frank the first few days of injection showed a decrease in rate of respiration, its magnitude being a little greater than the increase shown by Kambi. Adaptation to the effect was apparently complete by the end of the first week.

In neither animal was the deviation in respiration rate of significant size. Thus, within the limits of these few data, we can only conclude that morphine injections of this size have no definite effect on the respiration rate of chimpanzees.

(5) Metabolic rate. Chahovitch and Vichnjitch (1928) have reported that morphine increases the basal metabolic rate. Barbour, Gregg, and Hunter (1930) measured the basal resting metabolism of dogs during morphinism and withdrawal, finding that the former increased the metabolic level while the latter lowered it. They concluded that morphine is essentially a metabolic stimulant. Gulliksen (1931) also reported an increase in the metabolic rate of dogs given morphine injections, as well as a "conditioned" increase due to the injection situation. These results contrast with those of Anderson (1929), who observed human subjects for 1 hour following small doses of morphine (0.1 to 0.5 mg. per kg. of body weight) and found that the metabolic rate was somewhat lowered under such conditions, together with a slight decrease in respiration rate.

As part of the present investigation an attempt was made, in collaboration with Doctor J. M. Bruhn of the laboratory staff, to determine the effects of morphine doses on the respiratory metabolism. The apparatus and method used were those described by Bruhn and Benedict (1936) in their account of measurements of chimpanzee metabolic rate. Ten or more sets of measurements were made on Lyn and Velt, about half that many on Kambi, and none on Frank because of the briefness of his morphinism.

Pre-morphine determinations were made, for comparison with later measurements following morphine injections. Each deter-

mination represented the average of 3 or more 20-minute periods during which the animal was satisfactorily quiet, as indicated by concomitant activity records. The trials were made between 8 and 10 p.m., with the subjects in a "post-absorptive" condition.

The results showed that for Lyn metabolic rate during the evenings following an afternoon injection deviated but little from the pre-morphine values. At times he was too restless to allow satisfactory measures to be made. Velt was without exception too restless following an afternoon injection to permit satisfactory determinations to be made that evening. This restlessness involved the picking, hair-pulling, etc., which has been described earlier as a regular after-effect of the injection. Likewise, satisfactory determinations were not secured from Kambi.

Because of the induced restlessness, any effects which morphine injections might have had on the metabolic rate were thoroughly obscured. Our data do not justify any conclusions here.

(6) Nocturnal activity. A measure of the restlessness induced by morphine injections was secured by placing the animal in the metabolism cage overnight, with continuous recording of activity. For this purpose stylograph paper was substituted for the smoked paper activity records used in the metabolism experiments; it provided a satisfactorily detailed picture of the subject's activity during the course of the night. The assumption can be made that these records are also sleep records; very probably the animal is awake during periods of more or less continuous activity, and asleep during periods in which relative inactivity is broken only by brief, isolated deflections of the record line, due to the animal's turning over, shifting a limb, etc. It can also be assumed that a period containing several of these isolated deflections indicates relatively restless or light sleep, as contrasted with the more complete repose of those periods containing few or no deflections.

In view of the fact that several of the attempts to secure measures of metabolic rate following injections of morphine were defeated by the animal's excessive restlessness, a comparison was made between the amount of nocturnal activity following days

on which both morning and afternoon injections had been given, and days on which only the morning injection had been given. Since the primary effects of morphine do not last much more than 8 hours, this comparison can be said to contrast nocturnal activity while under the effects of a morphine injection with that in the absence of such effects, in the morphine-dependent chimpanzee. Two subjects, Lyn and Velt, were used here, and the measurements made about 3 months after morphine injections had been begun.

The results showed for Velt a much greater amount of nocturnal activity following an afternoon injection, but for Lyn the amount of activity was practically equal for the two conditions, considering the total amount of activity for the whole night. This difference between the two animals is in line with the findings in the previous section, in which it was reported that Velt was more restless than Lyn during attempts to determine metabolic rate following an afternoon injection. For both animals, however, it was found that there was considerably more activity from 7 p.m. until midnight for days on which an afternoon injection had been given, than for the other (no afternoon dose) days. The records indicated that their sleep was probably more "restless" at such times.

These activity records, together with the results secured from attempts to measure metabolic rate and the observations of general behavior, all indicate that injections of morphine of the sizes employed tend to produce restlessness in the morphine-dependent chimpanzee rather than sedation.

(7) Blood cell counts. Several investigators have reported effects of morphine on the blood cells. Forti (1926) found that it destroyed the ameboid movements of the leucocytes rather rapidly, and Ikonen et al. (1929) observed that the injection of morphine raised the leucocyte count of rabbits two and one-half times the normal value.

Plant and Pierce (1928) conducted an extensive investigation of blood cell changes during chronic morphinism and withdrawal in dogs, and found that during the morphinized state neither the erythrocytes nor the leucocytes were materially altered in num-

ber; during abrupt withdrawal, however, the number of red cells decreased while the number of white cells increased markedly, with a larger percentage of polynuclear neutrophiles present. The hemoglobin content remained relatively unaltered during morphinism but fell during withdrawal relative to the decrease in number of red cells. These investigators also cited a study by Morat (1911) on human addicts in which it was found that during addiction no marked changes in the number or the properties of red or white cells occurred. During withdrawal the red cell count increased somewhat, and the white cells increased markedly, due mainly to an increase in number of the large polynuclear cells.

In coöperation with Doctor John M. Bruhn blood cell counts were made on our subjects under the following conditions: prior to administration of morphine; during periods of regular morphine administration; and during periods of withdrawal. Red and white cell counts were made on each occasion and, in addition, slides were usually made for the determination of differential white cell counts.

The animals were trained to tolerate being stabbed on the end of the finger with a small lancet. One experimenter sat beside the animal on the work table, holding him loosely, and keeping his hand and finger in place for the blood-taking. The other experimenter then secured the blood sample, using the ordinary pipettes designed for this purpose. Figure 6 shows this procedure and illustrates the animal's coöperation.

In passing, it may be of some interest to report the difficulty which was encountered in getting sufficient blood from these animals for satisfactory samples, using this, the most feasible method. The skin of the chimpanzee's finger-tip is so thick and tough that a sharp jab of the lancet was necessary to draw any blood at all. An even more troublesome factor was the extreme rapidity with which the blood clotted, as compared with human blood. On several occasions one or more pipette samples were spoiled due to clotting, even though the experimenters worked rapidly and secured samples with a speed which would, for human blood, have reduced almost to zero the chances of clotting.

Fairly complete blood count data were secured on Lyn and Velt, and a few counts were made on Kambi. No blood cell counts were made on Frank.

The results showed that the number of red cells per cu. mm. was relatively stable under all conditions sampled. Administration of morphine, or its lack, had no apparent effect on the red cell count which was characteristic of each animal.
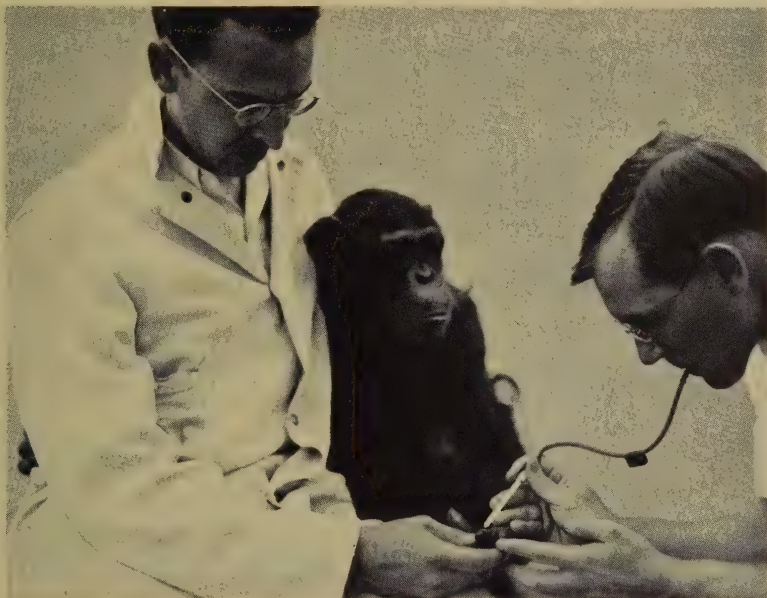
FIG. 6. Showing the coöperation of a subject (Velt) in the taking of blood samples from the finger, for making blood cell counts.

White cell count is a notoriously variable quantity in man as well as the higher animals. The number is increased greatly normally in the course of food absorption, and is increased greatly pathologically during infectious diseases. In the course of a day, during which food is ingested and absorbed several times, variations in white cell count will be considerable. For this reason, pathological or pharmacological causes of change in white cell number must produce a deviation of large amount in order to be distinguishable from the ordinary diurnal changes.

The data secured in the present investigation do not show any

clear effects of morphine administration on white cell count. For Velt there is evidence of an increase during morphine administration, but the fluctuations are great. A striking finding was the appearance of several extremely high counts in this animal. White cell counts as high as 30,000 per cu. mm. were found, 2 to 6 hours after morphine injection. Other observations at comparable times, however, frequently produced counts only half this size. The average of Velt's pre-morphine white cell counts is 8,450 per cu. mm.; the average of 16 different counts made during the first 3 months of morphine administration is 17,700 per cu. mm.

In contrast, white cell counts for Lyn and for Kambi showed very little, if any, tendency to be increased during morphinism. Our data thus compel us to refrain from generalizations as to the effect of morphine on the blood cell counts of chimpanzees.

(8) Pupillary changes. A commonly reported effect of morphine in human beings is a decrease in the size of the pupil; the so-called "pin-point pupil" has been one of the most publicized stigmata of the addict. During withdrawal, dilatation seems to predominate (Light et al., 1929), although other factors, such as the amount of illumination present, play a complicating rôle. In animals the reverse seems to be true. Many investigators have reported that their animals exhibited dilatation during morphine administration and constriction during withdrawal. A morphine mydriasis in cats has been reported by Gold (1929) and asserted by him to be independent of the excitement, and in monkeys (from heroine) by Seevers (1936a).

All four subjects of the present investigation regularly exhibited dilatation of the pupils following morphine injections. The effect usually appeared within a half-hour and persisted for four hours or more. Pupils were considerably enlarged, and fluctuated noticeably in size as one observed them steadily for several seconds in a constant light. No indications of photophobia were apparent. Little, if any, tolerance to the dilatation effect of the drug was observed. Six months and more of daily injections of the same amount of morphine still produced the characteristic pupil enlargement.

These findings corroborate those which have been uniformly reported for other infrahuman species. For man, constriction is the regular pupillary effect of morphine; he seems to be unique in this respect.

b. On behavioral tests. Animal experiments which have reported the effects of morphine on the "higher functions" have been comparatively infrequent. Most of the studies have been primarily concerned with pharmacological and related medical problems. In cases where behavioral observations have been reported they are, in general, supplementary to the other data presented.

There have been, however, a few animal studies which have directed attention to description of the behavioral effects of morphine, both in isolated doses and with chronic administration of the drug. Among these should be mentioned the experiments of Plant and Pierce (1928) with dogs; Tatum, Seevers, and Collins (1929) with dogs, rabbits, cats, and monkeys; and Seevers (1936a) with monkeys.

Experiments devoted primarily to studying the effects of morphine (and other opiates) on the psychological functions of animals, such as the acquisition and performance of a skilled act, have been even more rare. Macht and Mora (1920) studied the effect of morphine on the performance of rats in a Watson circular maze; Fromherz (1927) observed its effects on the visual discriminatory capacities of mice; Miles (1929) tested the performance of rats on an elevated maze after they had received doses of various drugs, among them morphine; and Simon and Eddy (1935) and Eddy and Ahrens (1935) also observed the effects of morphine and certain other opiates on the maze-running ability of rats. The results of these investigations agree in showing that morphine has a disrupting or inhibiting effect either (a) on the learning of a habit, or (b) on the performance of a learned act. In no case was the morphine shown to be responsible for any improvement in performance.

Several investigators have reported the appearance of conditioned reflexes—both glandular and motor—to the chronic administration of morphine. One of the first accounts of such phenom-

ena was presented by Collins and Tatum (1925), who reported
that after 7 or 8 daily administrations of morphine each of their
eight dogs showed profuse salivation and even, in a few cases,
vomiting *before* the daily dose was given. The entrance of the
experimenter into the dog room was often sufficient to set off the
salivation, and the sight of the hypodermic syringe "never failed
to produce a secretion of saliva." The authors asserted that
factors such as nausea, pain, or fear were ruled out in these
observations. After four months the dogs still salivated at the
sight of the syringe. In a further study Tatum, Seevers, and
Collins (1929) report additional data on some twenty dogs used
in chronic morphinism experiments, in all of which the conditioned
salivary reflex developed, and continued throughout the experi-
ment. Cats used in the same investigation also developed a well-
marked salivary reflex which the authors interpret as a "sign of
aversion." "At sight of a syringe or of preparations for injec-
tions saliva fairly runs from the mouth" (p. 456). Monkeys were
used, also, but the authors do not report any observations of
conditioned salivation in them.

The findings of Tatum, Seevers, and Collins were confirmed by
Kleitman and Crisler (1927) with dogs. They kept their animals
in stocks for various lengths of time before injections, and got not
only profuse conditioned salivation but also, at times, conditioned
retching and vomiting. These conditions were rapidly extin-
guished on discontinuance of the drug. They called this phe-
nomenon a delayed conditioned reflex. No "Pavlovian sleep"
was observed in connection with the phenomenon. The condi-
tioned salivary reflex could be abolished by starvation, and Crisler
showed in a later report (1928) that dehydration was the im-
portant factor in abolishing this response in chronically mor-
phinized dogs. Kleitman describes in a further report (1929)
some observations of the onset of sleep during morphine condi-
tioned salivation. Several other investigators have corroborated
the findings with regard to conditioned salivation and vomiting.

In the present investigation, as an attempt to observe and
measure the effects that morphine might have on the "higher
functions," the subjects were trained on several behavioral

problems prior to morphine administration, then retested at intervals after injections were begun. Comparisons were made of performances before and after daily injections of the drug.

Of the several experimental procedures which these animals had taken part in before receiving morphine, two, a delayed-response problem and a multiple-choice problem, seemed to offer the most favorable situations for comparing intellectual performance while under the effect of the drug with trials made while not thus influenced.

The delayed-response problem (D-R) and the multiple-choice problem (M-C) both possess the important characteristic of presenting a "continuous" problem to subjects; i.e., the organism must, in order to respond successfully on any given trial, observe the immediate situation and respond on the basis of cues presented on that particular trial. In maze problems, puzzle-box problems, and many others, the cues for successful response remain constant from trial to trial, but in the D-R and M-C problems, a specific stimulus pattern which served as the correct cue for one trial might very well lead to an incorrect response if followed on the next trial. It is in this sense that these two methods can be said to present a "continuous" problem, in contrast to the maze and other "constant situation" problems. This feature of the D-R and M-C problems lends itself well to comparisons of the effects of drug or of absence of drug on the performance of such a task. General practice effects are quickly levelled off in both problems, and do not persist as a disturbing factor in making comparisons of performance.

For both the D-R and the M-C problems, subjects were tested in an experimental room-within-a-room. This room, which has been described by Yerkes (1932), has wire-mesh walls, thus enabling the experimenter to observe an animal continuously; it also has a "work grille" next to which apparatus can be placed for experimental use. For the present problems the apparatus employed was the manual multiple-choice apparatus described by Yerkes (1927), and used extensively in these laboratories by Spence (1939) and other workers, in various multiple-choice and discrimination problems.

As the figure in Spence's report shows (1939, p. 9), this apparatus consists essentially of a long, narrow platform on which 11 small metal stimulus boxes are mounted, hinged in such a manner that they may be swung down out of the way behind the platform, or else rested on top of the platform in any desired combination. When resting on top of the platform a stimulus box effectively conceals the small piece of food reward placed under it; it can easily be pushed back on its hinge by the animal in order to obtain the reward. The platform has rollers at each end which run in tracks placed so that the platform may be pushed forward near the "work grille" within the animal's reach, or pulled back out of reach. A fiber-board screen may be lowered from above, cutting off the animal's view of the stimulus boxes during the delay period (D-R problem), or during the loading and setting of a combination of boxes (M-C problem). A one-way vision aperture in the screen enables the experimenter to observe the animal during delay periods and between trials.

(1) Delayed-response problem. For this problem, boxes no. 4 and no. 8 were used (after a brief use of no. 5 and no. 7 for part of the preliminary training). The distance between their inner edges was 60 cm.

The "direct" method of presentation was employed; i.e., the animal's attention was directed to the loading of the (to be correct) box with food, and to the placing of the other, empty, box on each trial. No trial was begun until it was clear that the animal had observed the loading. Reward was a small slice of banana or orange (approximately 10 grams), both of which were high in the food-preference hierarchy of all subjects throughout the investigation.

An experimental session consisted of 10 trials. During the preliminary training, delay periods ranging from 15 seconds to 60 seconds were used; on the basis of the results secured, it was decided to employ a 30-second delay during the formal tests, since it seemed to be the most favorable time interval for this experiment.

Lyn and Velt, the first two subjects, were given preliminary training until they mastered the problem to a criterion of 10

correct responses in 10 trials. Occasional retests, prior to the beginning of morphine administration, showed that mastery was retained without difficulty.

Daily injections of small doses of morphine (0.1 mg. per kg.) were started for these two animals Mar. 4, 1936, and gradually increased. The first series of D-R tests was given some 4 weeks later; performance shortly before the morning injection (16–18 hours since the previous dose) was compared with that a half-

TABLE 1

Delayed response test (30 seconds delay)

Subjects: Lyn, Velt, Kambi, and Frank. Summarizing the number of correct responses in the total number of responses made, on pre-dose and post-dose trials.

DATES	LYN		VELT	
	Trials before a.m. dose	Trials ½ hour after a.m. dose	Trials before a.m. dose	Trials ½ hour after a.m. dose
3/30/36– 4/ 7/36	27 in 30	30 in 30	26 in 30	20 in 30
5/ 1/36– 5/21/36	39 in 40	40 in 40	21 in 40	29 in 40
6/22/36– 6/29/36	33 in 40	40 in 40	20 in 40	31 in 40
10/21/36–11/ 2/36			18 in 40	29 in 40
Totals....................	99 in 110	110 in 110	85 in 150	109 in 150
	KAMBI		FRANK	
5/12/37– 5/13/37	10 in 10	10 in 10		
6/ 9/37– 6/12/37	17 in 20	18 in 20	19 in 20	18 in 20
7/ 7/37– 7/ 9/37	15 in 20*	20 in 20	20 in 20	20 in 20
Totals.....................	42 in 50	48 in 50	39 in 40	38 in 40

* Food motivation rather poor; inattentive and careless toward problem.

hour after the morning injection. Only one session was given each morning and a balanced sequence of conditions was followed. A similar series of comparisons was made during May and June, 1936, and again, for Velt, during October, 1936.

The results for Lyn and Velt are summarized in the first part of table 1. Examination of this table shows that Lyn performed somewhat better on post-dose trials during the first two series, although he did very well under both conditions. On the third (June, 1936) series, however, he became definitely poorer on the

pre-dose trials, although his successes here were still consistently above chance values. Velt's scores in the first series show some interference of the drug with D-R performance. This effect was soon reversed; the later series showed Velt to be considerably more accurate on post-dose trials, although he was not as accurate under either condition as Lyn was.

Observations of general behavior revealed characteristic differences under the two conditions. On post-dose trials the animal usually sat at the grille throughout the session, picking and scratching vigorously during the delay periods. This was especially the case with Velt. Close attention to loadings and prompt response were characteristic. On pre-dose trials, however, the subjects were very apt to pace about the experiment room during the delay period, and often had to be coaxed to the grille to observe the loading and to respond. They seemed less attentive and careful in their responses on these trials. Food reward was usually promptly accepted and eaten, but appetite seemed to be somewhat less than it was on post-dose trials.

Summarized results of D-R tests on the other two subjects, Kambi and Frank, are presented in the second part of table 1. It will be recalled that Kambi was started on morphine with doses of sedative size (2.0 mg. per kg.), while Frank was started with small doses which were increased rapidly in size until a dose level of 2.0 mg. per kg. was reached. Preliminary training was given in the manner described above for Lyn and Velt.

A comparison of pre-dose and post-dose performance shows that, from an initial equality in performance under the two conditions in May, 1937, Kambi became clearly poorer on pre-dose trials by July, 1937. Observational notes remarked that her appetite seemed less on pre-dose trials, that she was more apt on such trials to pace about restlessly during delay periods, and to be rather careless and inattentive in her responses.

Frank received morphine for only 6 weeks. The results for him indicate that, during this time, there was no interference of the drug with D-R performance, nor interference caused by its lack. There was no opportunity to discover whether with continued morphinism Frank, too, would have arrived at the condition of more accurate responses on post-dose trials.

(2) Multiple-choice problem. The problem presented here was "the middle box of three." Three adjacent stimulus boxes were presented on each trial, the middle one always being the correct choice. Three different settings were used: (1) boxes 4, 5, and 6; (2) boxes 5, 6, and 7; and (3) boxes 6, 7, and 8. Procedures in general were as described above for the D-R problem except that for the M-C problem 15 trials were given at each session. Preliminary pre-morphine training was given until each animal had satisfied a criterion of 15 correct responses in a session of 15 trials.

Table 2 presents the results of the M-C tests for the four subjects and compares performance on trials before the morning dose with that on trials one-half hour after the morning dose. The results in each case are expressed in terms of the number of correct responses per session of 15 trials.

The results for Lyn and Velt for the first two series show little, if any, difference under the two conditions. During the third (June, 1936) series both animals performed somewhat better on pre-dose trials. A good deal of this difference is due to the first post-dose session in that series, in which each animal got only 6 trials correct. A slight change which had been made in the apparatus before that session (a narrow strip fastened to the front of the sliding platform) may have temporarily disturbed the subjects. In a fourth series (Nov., 1936) Velt performed somewhat better on the post-dose trials.

The results for Kambi show, by the third series, a definite superiority of performance during post-dose trials. The protocols reveal that she was restless during pre-dose trials, paced about, and frequently had to be coaxed to work at the problem, while on the equivalent post-dose trials she responded willingly and carefully. Indications pointed to lowered food motivation and lessened interest in the problem during the pre-dose trials, thus corroborating similar findings reported above for the D-R tests.

Frank's scores, made during his brief 6 weeks' course of injections, reveal no definite effect of the drug, or lack of it, on this function.

In summing up these data secured from the D-R and the M-C

TABLE 2

Multiple-choice problem

Subjects: Lyn, Velt, Kambi, Frank.   Showing the number of correct responses (in each session of 15 trials) on pre-dose and post-dose trials.

DATES	LYN		VELT	
	Trials before a.m. dose	Trials ½ hour after a.m. dose	Trials before a.m. dose	Trials ½ hour after a.m. dose
3/23/36– 3/26/36	12 15	13 13	14 14	9 15
Totals....................	27 in 30	26 in 30	28 in 30	24 in 30
4/29/36– 4/30/36	14	15	15	14
Totals....................	14 in 15	15 in 15	15 in 15	14 in 15
6/ 8/36– 6/16/36	10 13 14 15	6 10 14 12	13 9 13 10	6 10 8 11
Totals....................	52 in 60	42 in 60	45 in 60	35 in 60
11/ 6/36–11/18/36			12 10 13 12	13 11 14 15
Totals....................			47 in 60	53 in 60
	KAMBI		FRANK	
4/12/37– 4/22/37	15 14 12	13 15 15		
Totals....................	41 in 45	43 in 45		
6/14/37– 6/18/37	13 15	13 15	7 14	11 10
Totals....................	28 in 30	28 in 30	21 in 30	21 in 30
7/10/37– 7/12/37	13 7	15 15	8 15	11 14
Totals....................	20 in 30	30 in 30	23 in 30	25 in 30

tests, a slight but fairly consistent superiority of post-dose performance over pre-dose performance is exhibited, after injection administration had proceeded for 6 or 8 weeks, or longer. Performance remains well above chance values on the pre-dose trials, however, indicating that the interference is not at all a serious one.

Explanation for the interference that was found seems to involve mainly the following two factors: (1) Restlessness due to lack of the drug; this restlessness was exhibited, at least in part, by a pacing about the room during delay periods and between trials. Loss of orientation, shifts in attention, and other distractions would certainly operate more strongly under such conditions than if the animals remained at the work grille throughout the session, as they usually did during the post-dose trials. That these subjects performed as well as they did on the pre-dose trials is evidence of the chimpanzee's ability to respond correctly in such situations without maintaining gross bodily orientation. (2) Decreased food motivation; it will be shown later that one of the prominent effects of prolonged withdrawal periods (48 hours or more) is a marked diminution of appetite and a sharp falling off in daily food intake. A noticeable amount of decrease in eagerness for food was present in the mornings before injections were given, after the injections had been maintained for 6–8 weeks or more. In the experiment room the subjects took and ate food reward more eagerly during post-dose trials than during pre-dose trials, after they had reached the stage where they were exhibiting, in their general daily behavior, a physiological dependence on the drug. Thus, in our experimental variation of the factors of dose and no-dose, we were very probably also varying the strength of food motivation, and our results are a product of these two sets of factors, at least.

5. The nature of the morphinized chimpanzee

a. General health, activity, etc. Small, constant doses of morphine do not appear to have been obviously deleterious to the health of animal subjects in many of the morphinism experiments which have been reported (Plant and Pierce, 1928; Hatcher

and Gold, 1929; and several others). With high levels of dosage, however, general debilitation has been observed (Faust, 1900, and others, on dogs; Kolb and DuMez, 1931, and Seevers, 1936a and 1936b, on monkeys).

Throughout most of the present experiment the health of the four chimpanzee subjects was entirely satisfactory. They experienced a few colds, but the incidence of colds appeared to be no greater for the morphinized animals than for the other chimpanzees in the laboratory colony. After having received morphine for 13 months Velt died following an attack of acute colitis; Lyn, after 7 months of morphinism, succumbed to a respiratory infection which was diagnosed at autopsy as lobar pneumonia. Neither of these deaths could be ascribed directly to the morphinism, since deaths from these causes have been recorded for other members of the laboratory colony. These two deaths, and the resulting autopsy reports, will be discussed in more detail in a later section.

General activity of the animals became less during the experiment than it had been; it also became more cyclical in nature. The subjects would display a good deal of restless pacing about their cages prior to the times when injections were regularly given, and also during the early stages of withdrawal periods. Following a dose, the animals would usually spend most of the rest of the morning, if not disturbed, in sitting quietly, absorbedly picking and scratching at various parts of their skin surface, with frequent hair-pulling.

The playfulness of these animals was noticeably less than is usually seen in adolescent chimpanzees. This effect was evident in all four subjects, but especially so for Lyn and Frank, who had been very lively, playful animals. During the first few weeks of drug administration, signs of playfulness, either toward the experimenter or toward other chimpanzees, almost completely disappeared. As the experiment went on, some return of playfulness was noted, especially in Frank and Lyn. The notes for Lyn record, during May, 1936, some signs of playfulness once more, especially at and just after the morning injection. Frank showed the same recovery, but in Velt and Kambi this effect was

much less evident. These two animals were much less playful and lively than the other two before the experiment was started. The differences are probably to be explained as characteristic individual "personality" differences between the several animals.

Together with this reduction of playfulness and activity, the drug seemed to produce a "social withdrawal" effect in the subjects. By that term the writer is attempting to describe the reduction of interest in other animals and activities with them— play, wrestling, tag, mutual grooming, etc. These activities, which were present in the subjects before the drug was given, suffered marked diminution during the experiment. A quotation from the notes kept for Kambi illustrates this, and is typical of the other subjects as well.

April 9, 1937. There has been a definite change in Kambi's interest in other animals, since the administration of the drug was started. Before, she used to become quite excited when led close to the cages of other animals, would grab at them, and frequently throw handfuls of pine-needles at them. Since she has been getting the drug this has entirely disappeared, and she pays very little, if any, attention to other animals. The drug seems to have made her more "introverted," if one may use that term for a chimpanzee!

This withdrawal from social interests and contacts was marked, and would very likely be described, if exhibited in human subjects, as a shift toward introverted behavior. As drug administration proceeded for several months, this tendency became somewhat less, but the subjects did not regain their pre-addiction interest in, and activities with, other animals.

b. Early signs of physiological dependence on the drug. With the beginning of daily injection of morphine, the behavior of the subjects was observed carefully each morning before injection was given, in order to detect the first signs of physiological dependence on the drug, which would be evidenced by the appearance of mild withdrawal symptoms. Especially detailed observations were made each Monday morning, since in these cases no injection had been given the preceding afternoon, and the animals had had no morphine for 21–22 hours. From time

to time, a dose was skipped or delayed, in order to bring to light any signs of dependence that might be present.

Description of the appearance of dependence will be given separately for each subject, since there were considerable differences in sizes of initial doses and in rates of increase in dose size.

Lyn. Daily injections were started March 4, 1936, with injections of 0.1 mg. per kg., twice a day, at which level the dose was maintained for the next three weeks, then gradually raised to 2 mg. per kg., and kept at that level for several months. On April 1, 1936, the morning dose was delayed about one hour, and when Lyn was brought to the injection room, he sat on the box quietly, and gave several deep, prolonged yawns. (See figure 7.) Such yawns are characteristic of humans during mild withdrawal. Immediately after the injection he yawned several times more, then lay stretched out on the box as if tired. Within 5–10 minutes, he became more lively, sat up, and began to pick at himself. No further yawns were observed. Within a few days after this first observation of dependence, it became noticeable that Lyn would cry and exhibit restlessness in the mornings when the experimenter came to his cage. He would continue to do so even after having been given his morning meal, but would cease doing so after the injection was given. Further evidences of dependence were observed on April 13, 1936. Excerpts from the notes for that day follow:

April 13, 1936. Lyn cried when I came to his cage at 9 a.m.; as usual, he was anxious to come from the cage with me. He had a good deal of perspiration on his face (this has been the case first thing in the morning for the past few days, but disappears later in the morning, even though the temperature is higher), and yawned deeply several times as rectal temperature was taken. His appetite was only fair. His morning injection was omitted and he was put back in his cage and observed for a half hour or more. There were now many drops of perspiration on his face, and he was yawning deeply about 2 or 3 times per minute. Hypersalivation was evident; he rolled saliva about in his mouth frequently, and on his lips; he sometimes put some saliva on the cage-floor, then licked it up again. Once he placed a quantity of saliva on his palm, then licked it off again. He showed a combination

FIG. 7

FIG. 8

FIG. 7, upper.   Withdrawal yawn (Lyn).   The mouth was usually held wide open for 3 or 4 seconds, then closed abruptly.
FIG. 8, lower.   Withdrawal yawn (Velt).

55

of restlessness and lethargy; spent most of the time lying down, stretched out as if tired, often closing his eyes as if to doze, but did not; he moved his limbs about frequently in a restless manner. Was irritable and less coöperative than usual during taking of blood sample and other observations.

The picture presented here agrees very well with descriptions given of mild withdrawal symptoms exhibited by human addicts, and clearly demonstrates Lyn's physiological dependence on the drug at this date.

Velt. The dates of beginning of injections, and the rate of increase, were the same as for Lyn. At the times when Lyn was beginning to show the dependence effects described above, however, none of these items was shown in Velt's behavior. It was not until April 20, 1936, following the omission of a regular injection, that signs of dependence were observed in Velt, as follows:

April 20, 1936. When I came to Velt's cage, at 10 a.m., to observe him, I found him stretched out as if to doze; he appeared sleepy and langorous. He frequently regurgitated food material into his mouth, then swallowed it again (he has a habit of doing this after a meal, but was doing it much more frequently this morning than usual). He yawned occasionally, not as widely as Lyn did, but yet it seemed to be abnormal behavior. He exhibited the same peculiar combination of restlessness and lassitude that Lyn did under similar conditions. There was a very slight amount of perspiration on his face.

Following this, signs of dependence on the drug were regularly observable in Lyn and Velt each Monday morning, and at other times when a dose was skipped or delayed. Within a few weeks, mild withdrawal signs became observable each morning, usually evidenced by restlessness, perspiration on the face, and excess salivation. Yawning was usually not produced unless a dose was skipped, or delayed for a few hours. (See figure 8.)

Experiments with other sub-human species, as well as observation of human cases, have shown that there are rather wide differences between individuals of the same species in their susceptibility to the effects of morphine, and the acquisition of dependence on the drug. Such differences seem to be illustrated

in these two animals. On the same dose regimen, diet, cage conditions, etc., Velt did not exhibit observable signs of dependence until almost three weeks after they had been observed in Lyn. Lyn, it is true, was in better general condition at the beginning of the experiment than Velt, but this fact might lead one to expect Velt to be the first to exhibit signs of dependence on the drug. At any rate, the difference in onset of dependence between these two animals was surprisingly large, considering the similarity of the regimen to which they were subjected.

Kambi. Daily injections were started April 5, 1937, with injections of 2.0 mg. per kg. once a day. After seven days this was split to 1.0 mg. per kg., twice a day; kept at that level until April 22, 1937, when it was raised to 1.5 mg. per kg.; then on May 1, 1937 to 2.0 mg. per kg., twice a day, and kept at that level for the next two months.

First signs of dependence in Kambi were observed on April 28, 1937, after a skipped dose. The notes record for this date:

She seems to be restless. She sat near the experimenter, and licked the soles of her feet, then the wire mesh; she seems definitely to have an excessive amount of saliva. She is also yawning frequently, most of them are not deep—the mouth is only half-opened—but they are persistent. A few deep, prolonged ones once in a while, however, like those shown by Lyn and Velt.

On May 3, 1937 (a Monday morning) Kambi displayed mild withdrawal symptoms, before injection was given: yawning, excessive salivation, some lethargy in behavior. She was eager, however, for the experimenter to take her from her cage. These signs became regularly observable on Monday mornings, thereafter, and indicated her growing dependence on the drug. She also became quite irritable in the mornings prior to injections, would cry when I approached her cage, and would frequently cry loudly, scream, and have a temper tantrum, if I took Velt before I took her. She was more uncoöperative and sometimes resisted manipulations, such as temperature-taking, prior to injection, but was satisfactorily coöperative after the injection had been given.

Frank. Daily injections were started June 2, 1937, with a

dose of 0.2 mg. per kg.   This was increased to 1.0 mg. per kg.
twice a day by June 4, 1937, and to 2.0 mg. per kg. by June 18,
1937, at which level it remained for the rest of the experiment.
On June 19, 1937, after a skipped dose, Frank was observed to
be somewhat restless and irritable, and to give several of the
deep, prolonged yawns so characteristic of mild withdrawal.
No perspiration was observed on the face.   On June 28, 1937
(a Monday morning), Frank showed the following symptoms: a
slight rhinorrhea, drops of perspiration on the face, unusually
large quantity of feces in the cage, heightened irritability, and
yawning.   These symptoms appeared regularly from this time
on, when a dose was needed.

   The times of first appearance of signs of dependence on the
drug can be summed up as follows: Lyn, 4 weeks after the begin-
ning of injections; Velt, 7 weeks; Kambi, slightly over 3 weeks;
and Frank, about $2\frac{1}{2}$ weeks.   These figures are obviously subject
to a considerable amount of experimental error, as some of the
signs of dependence may have appeared earlier than their first
recorded times, without being observed by the experimenter or
other members of the staff.   Since the experimenter had several
contacts with the subjects seven days a week, however, it is felt
that the magnitude of this error is not great; probably there is
not a significant difference between the time of appearance of
dependence symptoms in Kambi and Frank; but they very prob-
ably became dependent on the drug more rapidly than Lyn did,
and Lyn certainly became dependent much sooner than Velt did.

   Taking the values as given, we can state then that Frank, who
was started on small doses which were increased rapidly in size,
became dependent on the drug most quickly; Kambi, who was
given doses of sedative size to begin with, became dependent
almost as quickly, while Lyn and Velt who were started on very
small doses which were gradually increased in size became
dependent least quickly, but with a large difference between
them in the rate of acquisition of dependence.

   These values, ranging from somewhat less than 3 weeks to 7
weeks, are in line with the reports of the length of time needed
to induce dependence in dogs (Faust, 1900) and in monkeys

(Seevers, 1936a), and also agree with the findings in human clinical practice. The chimpanzee does not appear to be significantly different, either from man or from other of the higher mammals, in the rate at which it becomes dependent upon small daily doses of morphine.

c. First signs of desire for the morphine injection. With the demonstration in these animals of a physiological dependence on the drug (as shown by the appearance of abstinence symptoms when the injection is delayed or withheld), it has been established that the basic physiological effects of morphine on chimpanzees are highly similar to effects reported by other investigators for dogs, monkeys, and other higher mammals, as well as to observations made on the physiological effects of continued morphine doses on humans. Such a demonstration takes us to the stage which other chronic morphinism experiments have reached, but have not exceeded.

A primary purpose of this investigation, however, is to determine whether chimpanzees become genuinely addicted to morphine, over and above the induction of a dependence on the drug. That is, it is an attempt to determine whether, by continued doses of the drug, the animal will exhibit evidences of desiring the injection, and will behave in such ways as to achieve morphine injections, especially at times when such injections are needed.

Indications that these chimpanzee subjects desire hypodermic injection might be evidenced in several ways, and with varying degrees of definiteness: (1) by showing eagerness to be taken from the living cage by the experimenter, *at the regular dose times or when doses are needed*, in clear contrast to behavior exhibited when taken from the living cage at other times; (2) by struggling, under such conditions, to get to the room in which injections are regularly given; tugging at the leash and leading the experimenter toward and into that room; and exhibiting frustration when led away from the injection room and back to the living cage without having been given an injection; (3) by showing eagerness and excitement when allowed to get up on the box on which injections are regularly made, and more or less definite solicitation of the injection, by eager coöperation in the injection

procedure or even by initiation of the procedure itself; and (4) under controlled test conditions, choosing a syringe-containing box (whereupon injection is given) in preference to a food-containing box, either by opening the appropriate box, or by definitely orienting toward it rather than toward the other. The first three lines of evidence from general behavior will be discussed in this section. The experimental tests of desire for the morphine injection will be discussed in the following section.

All four subjects coöperated well in the injection procedure throughout the investigation; it will be recalled that they had been trained to such coöperation prior to any administration of morphine. Hence it will not be maintained in this report that passive coöperation for hypodermic injection is an indication that the animal desires the injection. The evidence is rather to be sought in active attempts to bring about the injection, or injection situation as a result of the animal's having learned that this experience is followed by cessation of withdrawal symptoms.

Since these evidences are necessarily based on qualitative descriptions of behavior, it will be necessary to describe briefly the initial appearance and growth of such behavior in each subject.

Lyn. For Lyn, the first definite evidence of desire for the morphine injection was recorded on August 1, 1936, nearly five months after the beginning of injections, and after a withdrawal period of some 40 hours. The following excerpt from the notes describes the first appearance of this behavior in Lyn.

August 1, 1936. Lyn whimpered and pulled at the leash when I tried to put him back in his cage after weighing. He then grasped the leash in his hand and pulled back toward the Maternity Building (in which the injection room is located). I let him lead me and he went back, between the Maternity and Nursery Buildings, looking in at each open doorway. He looked in through the open doorway of the injection room, then pulled me into the room after him, jumped up at once on the box (on which injections are regularly made), turned toward me and grunted several times. Then he stretched out full length on the box. When I attempted to get him off the box, and lead him from the room, he whimpered and grimaced, and tugged against me to remain

on the box. I tried once more, without success. Then I took him in my arms and carried him back to his living cage, without any protest on his part. However, he whimpered and cried when I put him back in his living cage, and then barked angrily and threateningly at me when I closed the cage door.

Shortly thereafter, Lyn was led to the injection room, and given an injection; then a few minutes later he was led back to his living cage without any protest. Similar behavior occurred a few days later during another short withdrawal period, characterized chiefly by unwillingness to be put back in the living cage without receiving an injection (no such resistance was encountered at other times) and tugging at the leash to lead the experimenter to the injection room. The following day, August 8, 1936, toward the end of this withdrawal period the following observation is recorded:

Leading Lyn back to his cage, I was forced to tug him along, as he was grasping the leash and trying to pull me toward the injection room. When I tried to put him in his living cage, he got loose, slipped between my legs and ran away toward the Maternity Building. He ran past the door of the injection room (which was closed) and entered the next open door of the building. I opened the door of the injection room as I followed him. When I caught up with him he took my hand readily enough, and I led him back. When we came opposite the open door of the injection room, he suddenly let go of my hand, went at once into the room, jumped up on the box, faced me, and grunted excitedly. I then carried him back to his cage. He protested and barked at me when I locked him in his cage. . . . A little later I took Lyn to the injection room. Again he jumped up on the box at once and grunted excitedly at me. He also grunted excitedly when I took the loaded syringe from the box, and came across my knee (into the injection position) very quickly, as soon as I put my foot up on the box.

This resisting the experimenter's attempts to return him to his living cage without an injection, during periods of morphine deprivation, became more definite and intense as the experiment progressed. The observations made on August 21, 1936, toward the end of a 47-hour withdrawal period, show the degree of

frustration that Lyn experienced when the experimenter refused to take him to the injection room:

This afternoon Lyn strenuously resisted—with tugging, crying, and screaming—my efforts to put him back in his living cage after having him out for temperature-taking. I led him around the back side of his living cage, and he tried to pull me away in the direction of the injection room. He was screaming loudly, then had a temper tantrum; the screaming ended in a glottal cramp, and he vomited a small amount of material. I led him back to his living cage and, with difficulty, got him inside.

Velt. Velt showed certain signs of eagerness with regard to the injection situation, at the same time as the first observations of this nature for Lyn. This was on July 31, 1936, after a withdrawal period of about 20 hours.

July 31, 1936. Velt was led back to his living cage, passing close by the open door of the injection room. He began to grunt and bark softly when we approached the open door, and looked in. I led him several steps past the door and he became quiet, following me with no sign of protest. Then I stopped and began to retrace our steps. He began grunting again and, walking ahead of me, entered the room and jumped up on the box. Then, facing me, he began to jump up and down on the box, vocalizing excitedly. When I led him from the room a few seconds later (without any injection) he came quietly and willingly; no sign of frustration.

The next day, the following observations were made, with Velt about 40 hours from his last injection.

August 1, 1936. After the weighing, Velt was led back toward his cage, by way of the injection room. He looked in as we passed the open door, then pulled on the leash, toward the injection room. I let him lead, and he entered the room, at once jumped up on the box and looked at me. Then after a few moments, during which I stood motionless, he turned and lifted the lid of the white (syringe-containing) box, and looked at the loaded syringe inside. After a moment he touched it, then started to pick it up (the first time this had ever occurred). I took the syringe from him, closed the box, and led him from the room back to his living cage. He came quietly and willingly, with no resistance.

For a considerable period of time, however, Velt did not show the active attempts to get to the injection room and the frustration at not being allowed to go there, that characterized Lyn's behavior (see above for August 8 and 21, 1936), even though Velt was on the same regimen and undergoing the same withdrawal periods as Lyn. The first definite instance of Velt's showing desire to get to the injection room when needing an injection, and frustration at being prevented from doing so, came during October, 1936, as the following notes show:

October 8, 1936.   For the first time today Velt showed definite signs of desiring to go to the injection room. He came eagerly as I took him from his cage; I led him around his cage building, then back to put him in his cage. Then I led him a short distance toward the injection room; he panted excitedly as he came quickly with me. I stopped about half-way to the injection room, turned and started back with Velt toward his living cage. He whimpered and pulled back, then grasped the leash in one hand, and pulled hard in the direction of the injection room. I let him lead me, and we came to the injection room, where he entered at once, and panted excitedly as he jumped upon the box.

After this appearance of tugging behavior, and whimpering when led away from the injection room when needing a dose, such behavior became quite regular. Several days later, October 16, 1936, as a control for this situation, the following procedure was followed:

Velt was taken from his cage at 10:30 this morning (about one hour after his morning injection), and I went through the same procedure of leading him a little ways away from his cage toward the injection room, then back to his cage again, a procedure which for the past few days has regularly induced pulling at the leash and whimpering, at times when he has needed an injection. On this occasion, however, Velt was completely indifferent as to which way I might lead him. He followed me quietly and willingly, and when I would stop, he would sit quietly, on the ground, with very little apparent interest in what was going on.

The intensity of Velt's motivation to be taken to the injection room when needing a dose became noticeably greater in the next

few days, indicating that the association between the injection room situation and relief from withdrawal distress was becoming stronger and more definite. On October 29, 1936, after being without morphine for about 20 hours, Velt exhibited the following behavior:

October 29, 1936. At 11:30 a.m. Velt was observed to be yawning deeply and frequently, and to be pacing restlessly. I gave him his noon meal and he ate parts of it, slowly. I sat by his cage, watching him. He came to the cage wall near me, panted at me, and obviously begged to be taken from the cage. I took the leash out of my pocket, and put it on my wrist (as if about to take him from the cage). He became very excited, stood close to the cage door, and panted excitedly. When I put the leash back in my pocket and sat down he began to whimper and cry. I stood up and walked away from his cage; he began to scream loudly, then had a glottal cramp, and vomited, with a series of rather strong abdominal contractions. . . . Later I returned and took him from his cage; he came very quickly and eagerly. When I stopped a short distance from his cage, turned, and started to lead him back, he tugged at the leash and pulled me strongly toward the injection room. He grunted excitedly when we entered the injection room, and immediately jumped up on the box.

This striving to get to the injection room became a regular item in Velt's behavior during subsequent periods of morphine need; in fact it was frequently a very difficult problem to get him back in his cage during the 48-hour withdrawal periods that were introduced at intervals. By tugging, screaming, and temper tantrums Velt would resist the experimenter's attempts to return him to his cage. Fortunately he did not exhibit any hostility toward the experimenter at such times, and never threatened to attack him; his motivation seemed directed primarily toward getting himself to the room in which he had learned that relief came.

Kambi. For Kambi, the first vague indication of wanting to be taken from her cage when needing an injection occurred on May 16, 1937, about 6 weeks after the beginning of daily injections. On this day she was fed her breakfast, but the morning injection was delayed for a while. Then:

She grimaced at me when I returned to her cage. I opened her cage door, leash in hand, pretending to be about to take her out, but instead closed the door and left. She cried as I walked away. I returned a bit later, and she came eagerly with me when I opened the door. I led her about the building, then back to her cage door. She cried as I put her in her cage. Later she came eagerly with me as I led her to the injection room, but showed no eagerness at entering the room, nor toward the syringe.

This reluctance to be returned to her living cage when needing an injection was noted several days later, following an omitted dose.

May 20, 1937. When I attempted to return Kambi to her cage, without giving her an injection, she refused to be put into the cage. She whimpered, cried, and tugged on the leash, then took my hand and pulled me away from the cage door. Then, crying loudly, she attacked the leash, biting it vigorously, but showed no hostility toward me. I let her lead me about the grounds, but she was uncertain about where she might want to go. After a few minutes I led her back to her cage and got her in.

On May 24, 1937, Kambi showed the first definite signs of desiring to get to the injection room. This was a Monday morning, and she had not had an injection for about 22 hours.

May 24, 1937. After weighing, I led Kambi back past the injection room. She looked in the open door as we passed. Several paces further on, I stopped and waited. Kambi remained motionless for several seconds, then grasped the leash with both hands and pulled me into the injection room. She headed toward the box, but I stopped her and led her from the room back to her cage. She came quietly, but cried when I left her. A few minutes later I took her from her cage, and stopped a few feet from the cage door. She at once grasped the leash, and very definitely led me to the injection room. I dropped the leash as we entered the room, and Kambi at once climbed up on the box, then turned and barked and panted at me excitedly. She came quickly across my knee as soon as she saw me pick up the loaded syringe.

After this, Kambi's desire to get to the injection room when needing an injection became stronger and unmistakably definite.

She would object strenuously to attempts to return her to her cage when she needed a dose, crying, screaming, and sometimes attacking the leash in her rage. Placing her in similar situations when a dose had recently been given did not produce this behavior at all; under such circumstances she was relatively indifferent as to where she was taken, or whether she was returned to her cage.

Frank. Frank was given morphine injections for only six weeks, hence there was much less opportunity for him to form the association between the injection room situation and relief of withdrawal symptoms than for the other three subjects. During short withdrawal periods on June 23 and July 1, 1937 (his injections were begun on June 2, 1937), he was unusually eager to be taken from his cage, and would ignore food given him, while he seemed to beg the experimenter to take him with him. He was quite excited when given the injections that ended these withdrawal periods, but there was no attempt made to get the injection, or no effort to enter the injection room.

Thus, of these four subjects the first three—Lyn, Velt, and Kambi— clearly indicated in their behavior a desire to get to the room in which injections were given, at times when an injection was needed, and did not exhibit this desire when there was no such need (that is, when an injection had recently been given). Frank very likely would also have done so, if his course of injections had been continued.

It should be emphasized that this desire to get to the injection room was not associated in any way with food motivation. The animals had usually been fed shortly before such observations were made, and more often than not, there were pieces of food still present in their cages at times when they would be begging to be taken from their cages. The animals were not fed in the injection room. It was used only for the regular morphine injections, which were almost always given with the animal standing on the large box in the room, and leaning over the experimenter's knee (see figure 1) and occasionally for measurements of rectal temperature (which were clearly not regarded as a "reward" by any of the subjects). Also, this struggling to

get to the injection room was exhibited only when the animal had been deprived of morphine for a considerable length of time, i.e., 20 to 48 hours, and was exhibiting the familiar syndrome of withdrawal symptoms. Observations made when the subjects had recently been given injections failed to produce any of this desire to get to the injection room, even though care was made to duplicate all other factors in the situation.

This general, more or less vague, desire to get to the injection room when needing an injection appeared a good deal earlier than any signs of a definite desire to receive an injection. This result is, of course, to be expected in terms of orthodox learning principles. The animals had regularly been injected in this room, while on this box, and had usually been kept sitting on the box for at least 10 minutes after the injection had been made. Thus withdrawal distress had been mostly, if not entirely, alleviated by the time the animal was taken from the injection room. This relief, having been regularly preceded by the recurring stimulus patterns which constituted the injection room, would thereby become attached to the injection room situation in general, and the animal's goal at this stage can be said to be to place himself in this situation in which, in the past, he has regularly experienced relief. What he has learned is a generalized pattern which is not, at this stage, specific to the hypodermic injection itself.

Later, when the injections came to be given at other places and under other conditions, among them the preference tests to be described below, the injection came to be the only regular antecedent of relief, and would thus come to be differentiated from other aspects of the injection room situation, which had proved themselves not to be invariable antecedents of relief from withdrawal distress. The differentiation of this response, involving a recognition of the function of the hypodermic injection in relieving withdrawal distress and a desire to receive the injection itself, will be described in the next section.

d. Experimental tests of desire for the morphine injection. The descriptions given above have indicated that the presence of a desire for the morphine injection appeared clearly in the general

behavior of the animals at times when a dose was needed. In
order to establish this fact beyond any shadow of reasonable
doubt, it seemed highly desirable to be able to express it in terms
of objective data secured from a well-controlled experimental
situation. To fulfil this purpose a choice-test was devised,
one in which the presence and the relative strength of desire for a
morphine injection could be measured objectively.

The choice-test presented to the animal a situation in which
he could select food or drug (i.e., the injection), but not both,
on any given trial. Thus the choice which he made could be
considered indicative of the relative strength of the two
motivations.

The apparatus used consisted of two wooden boxes, each one
30 cm. x 29 cm. x 16 cm. deep. One of the boxes was painted
black, and always contained a food reward, a small whole banana,
or half an orange; the other was painted white, and always
contained the hypodermic syringe, loaded with the regular dose.
Each box was mounted on a larger box, which served as a base
and raised the reward box some 20 cm. above the floor, thus
making it easier for the animal to manipulate. A hinged lid
covered and closed the top of each reward box; a false bottom of
galvanized metal made the inside depth of the box about 10 cm.,
and hence made the reward objects within readily accessible.
When the lids of the reward boxes were closed, a catch mechanism
locked them shut; when the release mechanism was actuated, a
pair of small window-spring bolts pushed the lid up a few milli-
meters, so that the animal could easily get his fingers under the
lid and raise it.

The lid-release mechanism was tripped by means of a wooden
stick-key, which fitted into a hole made in the front surface of the
box. The stick-key for the white box was circular in cross-
section, about 2.5 cm. in diameter, and 30 cm. long, and was
painted white; the one for the black box was triangular in cross-
section, about 2.5 cm. across and 30 cm. long, and was painted
black. Both stick-keys fitted snugly into the correspondingly
shaped holes of the two reward boxes and when inserted would
trip the mechanism and release the lids with but a slight amount

of pressure. The stick-keys could not be used interchangeably; the black key would not unlock the white box, nor would the white key unlock the black box.

Figure 9 shows the two reward boxes, with their stick-keys and characteristic reward objects.

The choice-tests were carried out in the experimental "room-within-a-room" in the Laboratory building, which has been
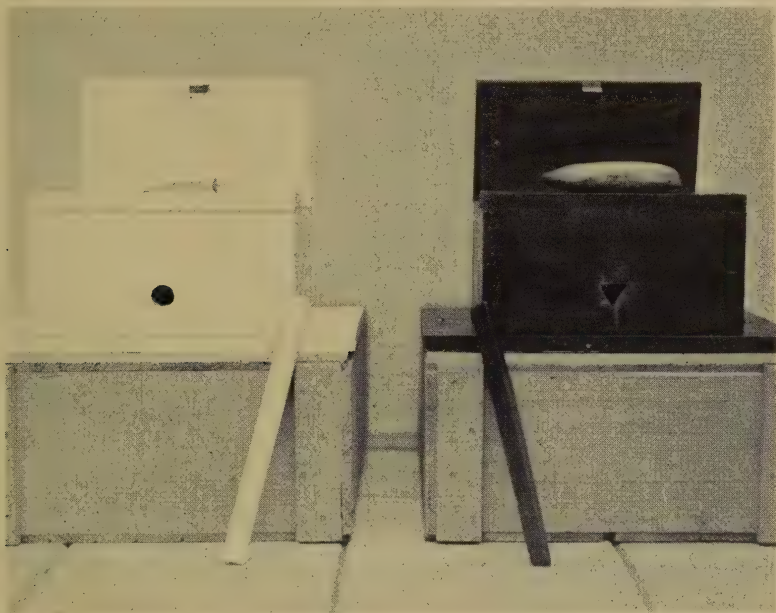
Fig. 9. The two reward boxes used in the choice-tests, with their respective stick-keys, and the reward objects found in each.

described earlier in this report. During the tests the two boxes were placed with their backs against the north wall of the work room, about a meter apart. In the middle of the south wall was a grille made of iron rods spaced about 10 cm. apart, through which the animals could reach in order to get objects outside. Outside the grille was a small wooden platform, 50 x 30 cm., mounted on rollers and set in a track. The two stick-keys were placed near opposite ends of this platform, about 35–40 cm. apart. A long wooden handle, fastened to the far side of the

platform, extended into the observation booth, which was about 1.5 meters away from the grille. By means of this handle the experimenter, who was concealed in the observation booth at the beginning of each trial, pushed the platform forward within reach of the animal at the grille, and allowed him to take one of the sticks. By pushing the platform forward so that it was barely within reach, the animal had to reach his arm through the grille as far as he could extend it, in order to grasp a stick.
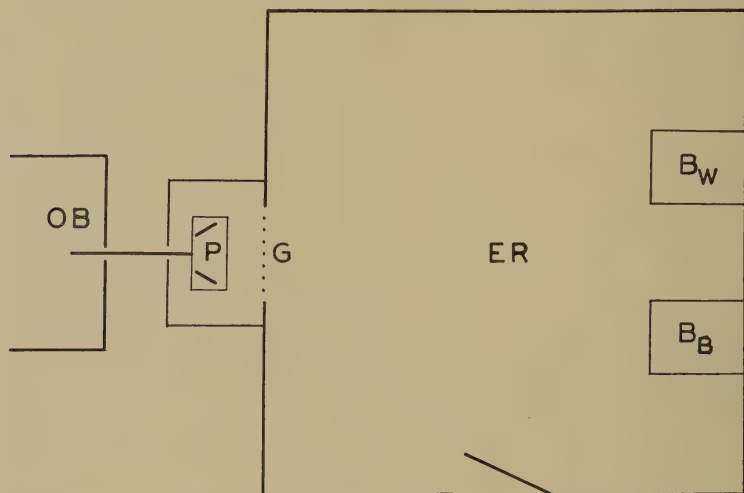
Fig. 10. Diagram of the choice-test situation. ER, the experimental room-within-a-room; B_W, the white (morphine-containing) reward box; B_B, the black (food-containing) reward box; G, the grille through which the animal reached; P, the movable platform on which the stick-keys were presented; OB, the experimenter's observation booth.

This was effective in preventing an animal from getting both sticks at once.

Figure 10 is a diagram showing the choice-test situation and the relationships of the important objects in the situation.

The tests were made after the animals had been receiving morphine for several months, were definitely dependent on the drug, and were exhibiting in their general behavior evidences of desire for the injection. It would have been interesting, in some respects, to test the animals frequently in this situation from the beginning of the experiment. It was felt, however, that the effects of frequent tests prior to the appearance of dependence

on the drug or signs of desire for the injection would probably create a strong bias in favor of the food choice, and that this would have interfered with and obscured the results of later tests. It was therefore decided to use the choice-test sparingly, and let its primary purpose be that of objectively testing for the presence of desire for the morphine injection, thus supplementing the evidence from general behavior.

Prior to the giving of the choice-tests, the subjects had had many opportunities to associate food with the black box, and syringe and injection with the white box; they had also been trained to manipulate the stick-keys and open the respective reward boxes. For the early preliminary training, a small portable black box and a white box were used. These boxes had no locks on the lids. Food was presented from time to time in the black box, and the syringe was regularly kept in the white box; thus the animals had many chances to see the syringe and the white box together at the daily injections. When the locked black box (the one to be used in the tests) was first introduced, the animals were trained by command, and by "putting through," to open it with the key and get the food reward therein. This was learned very quickly. Later, when the white box was introduced, the animals opened it on command readily, although not with the excitement with which they opened the black box; opening of the white box was always followed immediately by a morphine injection.

The formal tests were made under controlled conditions, using the four permutations of the following motivation variances: hungry; recently fed; needing a morphine dose; recently having been injected. "Hungry" and "needing a dose" are defined simply in terms of the time which has elapsed since the last feeding or the last dose, respectively. Thus the tests were given under the following four conditions: (1) hungry, and also needing a dose; (2) hungry, but recently injected; (3) recently fed, but needing a dose; and (4) recently fed, and recently injected. The times employed were usually 16–18 hours for the "needing" and "hungry" condition, and about one-half hour for the "recently" condition.

A test series was made up of 24 trials, 6 trials for each of the four different conditions; they were presented in a balanced order. Only one trial was given at each session, and usually only one trial per day. Two such complete test series were given to the subjects Velt and Kambi. Lyn, who had been given the preliminary training, died of pneumonia shortly before the tests were to have been given to him. Frank was not tested in this situation because of the briefness of his morphine experience.

The potentialities of the choice-test situation for demonstrating the presence of a desire for morphine injection can be summarized as follows: if the animals have learned to associate the injection with relief of withdrawal distress; if they desire the injection at times when they are exhibiting physiological signs of need for the drug; if an injection terminates, for a time, desire for another injection; and further, if the animals are capable of discriminating between the responses which will result in an injection and those which will make food available; if all this be true, then we should expect that our subjects will select the white syringe-containing box when needing a dose of morphine, whether hungry or not, and will select the black food-containing box after having recently been given a morphine injection. That is, the white box should be chosen on trials with conditions 1 and 3, and the black box on trials with conditions 2 and 4. For conditions 2 and 3 it is assumed that the recent satisfaction of a need will weaken response tendencies leading to it, in competition with responses which will lead to satisfaction of a need which has not recently been satisfied. For condition 1, it is assumed that in the morphine-dependent chimpanzee a 16–18 hour morphine deprivation will be a stronger motivating factor than an overnight (but also 16–18 hour) food deprivation. For condition 4, the prediction of a food choice is based on the assumption that the morphine injection will satiate temporarily the morphine need, but that the regular meal does not completely satiate food hunger.

Table 3 presents the results of the two test series for Velt, and table 4 comparable results for Kambi. The tables show the number of choices for each of the four motivating conditions that were in accord with expected predominant motivation, the number in opposition, and a few which had to be scored as equivocal.

TABLE 3
Results of food-morphine choice tests for Velt

CONDITION	RELATION OF CHOICES TO EXPECTED PREDOMINANT MOTIVATION		
	In accord	In opposition	Equivocal
First series (November 6 to December 1, 1936)			
1	5	1	0
2	6	0	0
3	4	0	2
4	6	0	0
Totals..............	21	1	2
Second series (December 14 to December 28, 1936)			
1	5	0	1
2	4	0	2
3	6	0	0
4	6	0	0
Totals..............	21	0	3
Combined totals (both series)...............	42	1	5

TABLE 4
Results of food-morphine choice tests for Kambi

CONDITION	RELATION OF CHOICES TO EXPECTED PREDOMINANT MOTIVATION		
	In accord	In opposition	Equivocal
First series (June 13 to 22, 1937)			
1	1	2	3
2	6	0	0
3	6	0	0
4	6	0	0
Totals..............	19	2	3
Second series (June 26 to July 6, 1937)			
1	5	1	0
2	6	0	0
3	6	0	0
4	6	0	0
Totals..............	23	1	0
Combined totals (both series)...............	42	3	3

A word of explanation regarding the equivocal choices is in
order here.   The choices which were so scored were occasions on
which the animal chose the "wrong" stick when the black stick
and the white stick were presented at the grille, but then took
this stick to the "correct" box and persistently tried to open it
with this stick, which fitted only the other box.   The animal
might spend the period attempting to open the "correct" box
and pay no attention to the other box (which could be opened
by the stick he possessed), or he might abandon his efforts to
open the "correct" box after several attempts, turn to the other
box and open it.   By way of illustration, the following protocols
are offered:

Kambi.   June 22, 1937.   Condition 1 (hungry, and needing a dose).
When the sticks were presented at the grille Kambi took S_B (the black
stick), but went directly to the white (morphine) box and tried several
times to open it with the black stick.   Finally she took the stick to
the black (food) box, opened it, and ate the piece of banana.   As soon
as she finished eating, she picked up the black stick and again attempted
to open the morphine box.   Then she went to the grille and reached
toward the white stick, which lay, out of reach, on the platform.   Trial
scored as "equivocal."

Velt.   December 12, 1936.   Condition 1 (hungry, and needing a
dose).   Velt took the black stick at once when the sticks were pre-
sented, but went at once to the white box with it, and tried to open it.
Dropped the black stick on the floor, returned to the grille, and sat
looking at the white stick, which was, of course, out of reach.   During
the rest of the 5-minute period he made several attempts to open the
white (morphine) box with the black stick, alternated with periods of
sitting at the grille looking at the white stick, and even reaching to-
ward it.   Was still trying to open the white box when the experimenter
entered and took him from the room.   Velt was very reluctant to
leave, whimpering, and tugging back against his leash.   Trial scored
as "equivocal."

The trials which were scored as "equivocal," of which the two
instances presented above are fair samples, were therefore
trials on which the animals were clearly motivated to open the
"correct" box for the conditions obtaining, but made an "error"

in that the wrong stick was chosen. In other words, they failed to discriminate correctly the crucial choice-response in the series of responses which would make the drug, or food, available. Such trials obviously should not be scored as behavior "in opposition" to expected predominant motivation, hence the "equivocal" category was established. However, in calculating the significance of the proportion of "correct" choices, "p" was taken as the proportion of "in accord" choices, and "q" the proportion of all other choices, whether "in opposition" or "equivocal."

Our chief concern with the results of the food-morphine choice tests is to determine whether the obtained results are significant, that is whether they indicate that the subjects were choosing the reward boxes on the basis of the motivating conditions established, or whether they were choosing in a manner not significantly different from "chance" selection. In order to disprove the "null hypothesis" (see Fisher, 1937, pp. 18 ff.) that the obtained proportion of "in accord" choices is to be explained simply in terms of "chance" factors (or, to state it in other words, that the different conditions established had no material effect on the choices made), it is necessary to show that the obtained results deviate significantly from "chance" expectation for the corresponding number of cases. Significance is established by demonstrating that the proportion of "in accord" choices lies beyond the limits of "chance" for the number of observations made.[2]

Table 5 presents the results of so treating these data. In every instance the obtained proportions deviate significantly from "chance," thus effectively disproving the "null hypothesis." The results are almost certainly not due to adventitious factors. Because of the conditions established, and the controls exerted, one is justified in concluding that the permutations of motivating

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[2] The basic formula for the standard error of a proportion, $\sigma_P = \sqrt{\dfrac{PQ}{N}}$, becomes $\sigma_P = \dfrac{.5}{\sqrt{N}}$ in order to express the standard error of "chance" for a given number of observations, when $p = q = .50$. $N - 1$ is substituted for N in the formula in the present calculations, because of the small number of cases. (See Guilford, 1936, pp. 77–79.)

conditions employed did in fact determine the choices made. In short, these two animals conclusively and objectively demonstrated their desire for morphine injections by appropriate choices in the experimental situation.

For Velt, the definiteness of the results is approximately equal in the two series, although the second series is free from any "in opposition" choices. This corroborates the general observation that Velt was fully addicted during both series of choice tests. For Kambi, however, the results of the second series are

TABLE 5

Showing the significance of the results of the food-morphine choice tests

SERIES	TOTAL NUMBER OF CHOICES	σ OF "CHANCE"	PROPORTION OF "IN ACCORD" CHOICES	DEVIATION FROM "CHANCE"	CHANCES IN 100 THAT DEVIATION IS SIGNIFICANT
Velt					
				σ	
I	24	.10	.875	3.75	99+
II	24	.10	.875	3.75	99+
Combined......	48	.07	.875	5.36	99+
Kambi					
I	24	.10	.792	2.92	99+
II	24	.10	.958	4.58	99+
Combined......	48	.07	.875	5.36	99+

much more definite than for the first series, suggesting that her addiction was increasing during the course of the tests.

An inspection of tables 3 and 4 reveals that on tests when recently injected (conditions 2 and 4) the subjects never had any trials in opposition to expected predominant motivation. When morphine-need was satisfied, food was definitely chosen in preference to another injection.

All of the "in opposition" choices that did occur were on trials with condition 1 (hungry, and also needing a dose). This is true for both subjects. Condition 1 opposed a food deprivation of 16–18 hours with a morphine deprivation of the same length

of time. The combined results for both animals show that on condition 1 there were 4 "in opposition" choices, 4 "equivocal," and 16 "in accord." Under the conditions of the present test it is clear that the motivation induced by a 16–18 hour morphine deprivation is predominant over that produced by a 16–18 hour food deprivation.

That the two motivating conditions are not entirely independent of each other is indicated elsewhere in this report (p. 107), where the diminution in appetite during prolonged (40–48 hours) withdrawal periods is described as a regular item in the withdrawal syndrome. However, it was well established that both subjects would eagerly accept and eat food (e.g., pieces of orange and banana, such as were used to bait the black food-box) 16–18 hours after having had a morphine injection, when it was presented to them in the living cage or elsewhere. But when confronted with the food-morphine test situation, in which food or drug, but not both, could be chosen, the preference was definitely in favor of the drug. Thus the choice can be maintained to be a choice between two "positive" motivations, and not simply due to a lack of food motivation under condition 1. This assertion is further borne out by several instances in which the animal, having chosen the white stick, opened the white box, and received his morphine injection, would sit quietly in the experimental room for a few moments, then take the white stick and attempt to open the black (food) box with it. One can justifiedly infer from this behavior that food motivation was present, even though the physiological effects of the drug had not yet begun to be effective.

As for condition 3, in which the animals needed a dose but had recently been fed, the preference is even more definite: 0 choices "in opposition," 2 "equivocal," and 22 "in accord."

On the basis of the results reported in this section, it can be maintained that a genuine addiction to morphine has been clearly and objectively demonstrated in these two animals. The test results corroborate and quantify the observations from general behavior that the subjects not only become dependent on continued administration of morphine, but actively strive to bring

that condition about, and seek it as a goal in preference to a food-goal, when the two motivations are opposed under the conditions of the experiment.

e. Performance on behavioral tests. Effects of the drug on performance in a delayed-response problem and a multiple-choice problem have been described in an earlier section. In addition to these learning and memory tests, an attempt was made to measure, in a thoroughly morphinized chimpanzee, the promptness with which work would be performed or the relative amount of work which would be done, in a given task which on some trials was followed by food reward and on others by drug rewards. The situations were such that it was always perfectly evident to the animal on each trial what the reward would be if he performed the task.

Two different work tasks were employed: a box-stacking problem and a "pull-in" problem. Only one subject, Velt, was used here.

(1) The box-stacking problem. In a recent article Yerkes and Spragg (1937) reported experimental procedures and results of testing young chimpanzees on several box-and-suspended-lure problems. One of these problems was chosen for use here: the two-box problem, the solution of which requires that the animal stack the two boxes under, or nearly under the suspended lure, mount the boxes, leap, and secure the lure (a whole banana). Apparatus and procedures were as described in the report mentioned above, except that in the present experiment the suspended lure was either the white stick-key (which opened the syringe-containing box) or the black stick-key (which opened the food-containing box).

A successful trial required that the animal stack the boxes under the lure, mount them and secure the lure (a stick-key), then go to the grille, open the reward-box there, and get his reward. On "food" trials a piece of fruit was placed in the black reward-box, which was lashed in place at the grille, and the black stick-key was the suspended lure. On "drug" trials the white stick-key was the suspended lure, the white reward-box was at the grille, and in it the morphine syringe was placed. On these

trials the morphine syringe was also in a small white celluloid container (a toothbrush holder) lined with absorbent cotton. This precaution was taken to protect the syringe and needle; the animal would pick up the container after opening the reward-box, and would at once bring it to the experimenter, who was seated on the floor at the far side of the room during the trials, and who would then open the container and give the animal an injection.

TABLE 6

Velt's performance on a box-stacking problem (two boxes), given as a work task to compare performance with food reward with performance with drug reward

Times are given in minutes and seconds

TRIAL	DATE, 1937	TIME	TIME TO SECURE STICK	TIME TO OPEN BOX
Trials with drug reward				
1	March 30	9:10 a.m.	6:25	6:45
2	March 31	9:15 a.m.	2:35	2:46
3	April 2	9:20 a.m.	1:08	1:15
Trials with food reward				
1	March 30	11:45 a.m.	Failed; 15 min.	
2	March 30	4:30 p.m.	Failed; 15 min.	
3	April 1	9:30 a.m.	Failed; 10 min.	
4	April 1	11:30 a.m.	0:30	0:36
5	April 2	11:50 a.m.	Failed; 15 min.	

Velt was the only drug addiction subject available that had also received training on the box-stacking problems in the previous experiment (Yerkes and Spragg, 1937): the two-box problem was thus one that he had already learned, and further trials on it would be work tasks rather than learning tasks, i.e., they would be indicators of the amount of motivation present toward performing the act.

Trials with food reward and with drug reward were given as shown in table 6. The drug trials were given shortly after the morning feeding, but before any injection had been given, the animal not having had morphine for 16-18 hours. Food trials

were given just before one of the regular feeding times, when the animal could be expected to be hungry and much interested in the prospect of food; morphine need was not present during the food trials.

Time was recorded from the introduction of the animal into the experimental room until he secured the stick, and also the time from the beginning until he had opened the reward-box.

The results, as presented in table 6, show clearly that Velt was much more strongly motivated on the drug trials than on the food trials. The protocols and the time records show that he worked promptly and eagerly during the three drug trials. On four of the five food trials he did not stack the boxes and get the stick-key before the end of the observation period; on the other trial, however, he secured food promptly (which showed, at least, that the food situation did operate as a reward). During the rest of the food trials he would show some interest in the suspended stick-key; on trial 1 he moved the boxes to a point below the suspended stick, and, standing on a box, reached toward the stick, but did not leap; on trial 2, he stacked the boxes below the suspended stick, got on them and reached toward it, but would not leap (whereas on all the drug trials he had leaped promptly and secured the white stick as soon as he had the boxes stacked). On both these food trials he spent some time trying to open the black reward-box at the grille, without a stick-key, by tugging at the lid of the box.

These observations indicate that food motivation certainly was not absent during such trials, but a comparison of the general behavior exhibited during food trials and during drug trials shows clearly that motivation toward drug reward was stronger than that toward food reward, under the conditions tested; this was indicated by such behavior as greater amount and persistence of effort, and signs of eagerness and excitement when an injection was impending in the situation.

(2) The "pull-in" problem. For this problem the experimental room which had been used for the box-stacking problem was again used. Outside the grille was placed a shallow track in which one of the reward-boxes could be placed. The box would

slide forward easily in this track when pulled or pushed. To the front of the box was attached a rope, long enough to lead through the grille and into the experimental room. At the back of the box was a short rope with a ring on the end of it. This could be slipped over a hook at the back end of the track; when this was done the reward-box could not be pulled in near the grille. When the rope was not hooked onto the box, the animal could grasp the front rope, pull the reward-box close to the grille, and use the stick-key to open it and get the reward therein. The animal could not see on any given trial whether the box was hooked or not; i.e., he had to discover by pulling, whether or not it could be brought within reach. The preliminary trials showed that Velt would readily pull in either the black (food) reward-box, or the white (drug) reward-box, whichever happened to be placed on the track. The purpose of the tests which were given here was to determine whether Velt would pull in a box faster and open it more quickly and with greater eagerness if it contained food reward or drug reward; and secondly, on the "frustration" trials (the trials in which the box was hooked, so that it could not be brought within reach), whether the animal would show more frustration over not being able to get drug reward than food reward, and whether he would work at the task under such conditions a greater proportion of a 10-minute period when the drug reward-box was present than when the food reward-box was present.

Four trials were given under each set of conditions: drug, rewarded; food, rewarded; drug, frustrated; and food, frustrated. The trials were presented in balanced order. The animal was adequately hungry or needing a dose, on all trials, depending upon the trial being given.

Table 7 presents the results of these trials. Records were secured of the length of time that it took the animal to pull the reward-box within reach and the time at which he got the box open, on each rewarded trial. On the frustration trials, a record was kept of the amount of time that the animal spent in pulling at the rope and working at the problem, during the 10-minute period, and also the time at which the animal ceased working at

the problem and did not return to it again before the end of the period.

The table shows that Velt, on the rewarded trials, worked just about as promptly for food reward as for drug reward. The average time to pull the box within reach is 7 seconds for both; the average time to get the reward-box open is only slightly less for the drug-reward trials, 21 seconds as compared to 23 seconds for the food-reward trials.

The chief difference between behavior on the food and on the drug trials is seen for the frustration trials. For the four

TABLE 7

The "pull-in" experiment

Comparing the responses to frustration of food reward with frustration of drug reward.   10 minute work periods

| | TRIALS WITH FOOD REWARD-BOX | | | | TRIALS WITH DRUG REWARD-BOX | | | |
| | Rewarded trials | | Frustrated trials | | Rewarded trials | | Frustrated trials | |
TRIAL	Time to pull in box	Time to open box	Amount of time spent in pulling and working	Time of ceasing to work	Time to pull in box	Time to open box	Amount of time spent in pulling and working	Time of ceasing to work
1	0:10	0:48	5 minutes	7:35	0:10	0:32	9 minutes	Till end
2	0:08	0:18	2:05	3:10	0:05	0:15	3:30	5:30
3	0:05	0:10	0:30	9:25	0:07	0:20	1:30	4 minutes
4	0:05	0:17	0:45	3:10	0:06	0:18	1:00	2:15

Times are given in minutes and seconds.

frustration trials with the food reward-box present, Velt spent a total of 8 minutes 20 seconds trying to get the box within reach; on the four drug frustration trials he spent a total of 15 minutes, nearly twice as much time. It should be noted that this is not to be attributed to a drug frustration trial being the *first* frustration trial of the experiment. The first frustration trial, which provided the animal with his first experience of not being able to get the reward-box within reach, was a food frustration trial. The table shows that Velt spent 5 minutes out of the 10-minute period in trying to pull the box in, but that he stopped trying after 7 minutes 35 seconds, and did not work at the problem during the last 2½ minutes of the period. The first drug frustration

trial came on the next day, and the table shows that Velt spent 9 minutes of the 10-minute period in trying to pull the reward-box in, and was still trying when the 10-minute period was over.

The protocols and observations of general behavior do not reveal markedly different pictures for the two kinds of frustration trials. In both cases the animal was apt to whimper when he discovered that the box did not come in when he pulled on the rope. Mouthing and even biting of the rope were fairly common on both sets of frustration trials. Restless pacing about the room often followed a period of tugging at the rope. Toward the end of frustration periods, Velt would usually ignore the situation and sit quietly, picking at his wrist or leg. This was a means of "going out of the field" which he employed in a wide variety of situations when frustration and unrelieved tension were experienced.

The two sets of observations which have been reported in this section have provided evidence which corroborates and extends the findings from the choice-tests described in the previous section. In general, a more prompt and vigorous expenditure of energy to achieve a drug injection reward than a food reward has been shown, and also a greater persistence of effort in the face of frustration, if the possible reward is drug rather than food.

f. Effects on sexual functions. Morphine is reported to act regularly as an anaphrodisiac in man, diminishing both sexual desire and potency. With continued addiction complete impotence is asserted to ensue, as well as sterility. In the female addict menses diminish and cease, and there is a regression of secondary sex characters. Fertility is diminished, and where pregnancy does occur, there is increased frequency of abortion (Terry and Pellens, 1928; Magid, 1929). Clinical observations, as well as information gathered by questioning, indicate that sexual intercourse among married male addicts usually occurs in the morning soon after awakening, seldom in the evening after retiring. This is because the addict awakes in the morning with a need for another morphine dose, i.e., is suffering mild withdrawal distress, which is characterized by hyper-irritability of many of his action systems, among them the sexual. In the

evening, however, an injection is commonly taken between the evening meal and retiring, thus sexual excitability is diminished at this time.

During a prolonged or a complete withdrawal from the drug, addicts exhibit many striking sexual effects which have been described by several writers (Terry and Pellens, 1928; Light et al., 1929; and others). In the male, continued erections of the penis and seminal emissions are commonly observed during certain stages of the withdrawal; in the female "spontaneous" orgasms are apt to occur at such times.

The effects of morphine and its deprivation on the sexual functions of human addicts thus correspond quite closely with its effects on other aspects of organic functioning; doses of the drug act as a depressant or sedative, but with the onset of addiction, withholding the regular dose leads to a hyper-irritability of many functions, especially those involving smooth muscle systems.

Several investigators have described various effects of morphine on sexual functions of animals. Forster (1928) reported that morphine did not appear to alter the estrous cycle in rats. However, Plant and Pierce (1928) found that there were no evidences of "heat" in any of their morphinized dogs, indicating that the drug had interrupted the sex cycle; three of their dogs, pregnant when injections were started, gave birth to pups in a normal manner.

Tatum, Seevers, and Collins (1929) reported that their female dogs showed signs of nymphomania during acute withdrawal from morphine, and that their monkeys exhibited priapism at such times. No further description of effects on sexual behavior is given in this report. The protocols for Kolb and DuMez' morphinized monkeys (1931) indicate that during withdrawal from the drug masturbation was frequent and excessive, but no other observations of sex behavior are reported.

Seevers (1936a) reported that in his heroinized monkeys sexual activity subsided during drug administration, and that sexual play or masturbation was rarely observed. Menstrual bleeding ceased immediately on administration of the drug, to reappear during a protracted withdrawal period, although a

certain amount of cyclic reddening of the sexual skin persisted if the doses were not too large. As part of the syndrome of acute withdrawal from the drug, Seevers reported observations of erections and continued masturbation.

In the present study, the sexual immaturity and inexperience of most of the subjects used prevented the making of a complete and detailed series of observations on the sexual effects of morphine in the chimpanzee. Live sperm had been observed in the ejaculate of both Velt and Frank prior to the beginning of the morphine experiment (by means of examination of the jelly-like plugs which could be recovered after the animals had induced ejaculation by masturbation). Velt, however, was the only one who had had complete copulatory experience with mature, receptive females. Lyn, the third male, was adolescent, but sexually immature at the beginning of the experiment (i.e., as far as could be determined; he had never been observed to have an ejaculation as a result of masturbation, and had not copulated when given the opportunity to do so). Kambi, the fourth subject, and the only female, was adolescent but sexually immature at the beginning of the experiment. Menstruation had not occurred, and very probably no ovulations had taken place. She had never been mated with a mature male, and was, therefore, sexually inexperienced.

(1) Effects on erections and on genital swellings. In the male chimpanzee, it is a common observation that erections of the penis may accompany many other states of excitement than specific sexual excitement; the appearance of food, the presence of strangers, or even frustration during an experimental session, are frequently accompanied by erections. Early in the experiment it was noted that in all three male subjects erections were regularly appearing a few minutes after a morphine injection, and were apt to persist, with varying degrees of penile engorgement, for an hour or longer. This effect became more definite as the animals became more and more dependent on the drug.

During withdrawal periods the frequency and duration of erections were sharply diminished; they were extremely rare during the latter part of 48-hour withdrawal periods, even when

attempts were made to excite the animals by showing them food or sexually receptive female chimpanzees.

The injection which ended a 48-hour withdrawal period was almost invariably followed in a few minutes by a strong and persistent erection, in striking contrast to its absence during the period of acute withdrawal.

These effects are in marked contrast with the effects reported for human addicts. The writer does not have any satisfactory explanation for this difference, although it does seem to be related to certain other contrasts between human and chimpanzee responses to morphine. This topic will be developed further in a later section.

In the female chimpanzee, as in many other infrahuman primates, the sexual skin and surrounding area undergo a cyclical swelling which is related to the estrous cycle. The sexual skin is detumescent and flaccid during menstruation and for several days thereafter. Then a swelling appears and increases in size and tenseness. Its maximum coincides roughly with the occurrence of ovulation and the period of greatest sexual receptivity, then diminishes abruptly and remains in a resting state during the remainder of the cycle. Elder and Yerkes (1936) have reported in detail many of the important characteristics of the estrous cycle in chimpanzees.

Kambi's first sexual skin swelling occurred in December, 1935, while she was in the laboratories in New Haven, some 15 months prior to her use in the morphine investigation. From that time until the beginning of morphine injections 11 periods of slight to moderate sexual skin swelling had been observed, indicating that Kambi was approaching sexual maturity and, in the normal course of events, could have been expected to begin menstruating within a few months.

Daily morphine injections were begun during April, 1937, and continued, except for brief withdrawal periods, until the middle of July. During that time Kambi exhibited no sexual skin swelling whatsoever, even during the 48-hour withdrawal periods. The withdrawal periods were probably too short to permit any effects to become manifest.

On July 11, 1937, Kambi received her last morphine injection, undergoing a complete abrupt withdrawal from the drug.   On July 20 a slight genital swelling was noted, which increased rapidly in size and reached a maximum on July 28.   This maximum (with an estimated volume of 250–300 cc.) was a larger swelling than Kambi had ever had before; it persisted until August 8.   It was somewhat, but not completely, diminished between August 8 and 19, then abruptly returned to maximum size and remained in this state for an unusually long period of about 24 days.   A quiescent period then followed, which was broken by a period of genital swelling some 28 days later, and another 20 days subsequent to that.

With the onset of genital swelling after morphine withdrawal, Kambi exhibited greater sexual excitability and sensitiveness than she had for some months, including increased amount of clitoris stimulation, and evidence of pleasure in having rectal temperature taken.

These observations on Kambi show considerable agreement with effects reported for human female addicts, provided it is realized that Kambi did not become strongly addicted, and was not sexually mature.

(2) Effects on the spermatozoa.   Data on this topic are limited to Velt; Lyn was sexually immature, and Frank, although sexually mature, had not been mated successfully with receptive females before or during the morphine investigation, and moreover, received the drug for only 6 weeks.

Motile sperm had been reported in ejaculate samples from Velt (following auto-erotic behavior) as early as the spring of 1935, and this observation was corroborated at subsequent times during the remainder of his last year in New Haven.   The first observation in Orange Park did not come until August, 1936 (following copulation), and was some 5 months after the beginning of morphine injections.   Between August and November, 1936, there were five occasions on which microscopic examination of Velt's sperm was made, following successful matings.   These examinations revealed an abnormally small number of sperm; of these 95 per cent or more were non-motile, and the motile ones

relatively sluggish. This picture contrasts sharply with the great density of population and marked vigor of movement of sperm samples secured under similar conditions from normal adult male chimpanzees of the laboratory colony. The conclusion would readily be drawn that Velt was probably sterile.

However, during December, 1936, and January, 1937, some additional findings came to light. Several opportunities occurred for examining samples of ejaculations which occurred within a half-hour or so of each other, due to multiple copulations during a mating period, to masturbations, or to both. In these cases it was discovered that a sample from the first ejaculate contained only a small number of sperm, most of which were motionless, and the rest having little vigor of movement; samples from a closely-following ejaculation, however, revealed fairly large numbers of sperm, most of them quite active.

There were six such cases, and they seem to indicate definitely that live and active sperm were ejaculated by Velt on occasions which closely followed prior ejaculation, and also that the sperm ejaculated at such times seemed as active as those of a normal adult chimpanzee.

These findings pose a very interesting question. If the chronic administration of morphine was responsible for the pathological picture which examination of Velt's sperm revealed, why should this effect not remain relatively constant in other samples than the first ejaculation, when two or more occur within a short interval? Why should the sperm in the first ejaculate be motionless or very sluggish, while those from an ejaculation 10 minutes later are not only much more numerous but contain a considerable proportion of highly active specimens?

(3) Effects on mating behavior. In view of widespread clinical reports of the effects of morphine on the sexual life of human addicts, it was felt that an important part of the present study should be the investigation of the effects of morphine, and its deprivation, on mating behavior. Here, as in the previous section, the results are limited to the subject Velt. The other subjects were either sexually immature or sexually inexperienced throughout the investigation.

Although several opportunities had been given previously, Velt's first successful copulation did not occur until August 11, 1936, slightly over 5 months after the beginning of morphine administration. Following this initial success, he quickly learned to copulate readily and effectively when given opportunity.

At the time of his first copulation Velt was not only dependent on morphine injections, but was beginning to show a positive desire for the drug. Thus, there are no data bearing on mating behavior prior to dependence on the drug. It is regrettable that such "base-line" data are lacking, but various exigencies of the investigation made this impossible.

Following several preliminary, more or less "informal" mating experiences, designed to provide Velt with experience and skill in this function, a series of controlled matings was carried out, extending from January 12 to April 22, 1937. Three young adult female chimpanzees served as sexual partners for the male. Each was used only during periods of presumably greatest sexual receptivity. There was no evidence that Velt definitely preferred any one of them as a sexual partner; under comparable conditions he copulated with each with equal willingness.

The principal variable factor in the controlled matings was the time which had elapsed since the last morphine injection. They were distributed as follows:

Time since last injection, in hours	Number of matings
1	6
2	6
5	5
16–18	5
24	6

There were also several mating opportunities presented between the 24th and 48th hours of the 48-hour withdrawal periods. Velt refused without exception to copulate at such times, as will be described below. The main body of data thus ranges from 1 hour to 24 hours after injection.

The general procedure followed for the matings was that which has been regularly used for experimental investigations of chimpanzee sex behavior carried out in these laboratories (see Yerkes

and Elder, 1936). Observational notes and measurements were recorded on a "Controlled Mating Record" which was regularly used for this purpose, and is essentially the form shown by Yerkes and Elder (1936, p. 36). The form provides for description of the status and caging of both animals, the pre-mating behavior, evidences of dominance, timidity, sexual excitement, etc., as well as a detailed description of the copulations, including their number, the time elapsing between intromission and

TABLE 8

Measurements of various aspects of mating behavior for matings made at times ranging from 1 to 24 hours after morphine dose

Subject: Velt

The mating period was 10 minutes in length. (There are 6 matings each for the 1 hour, the 2 hour, and the 24 hour periods; 5 each for the others.)

TIME SINCE LAST MORPHINE DOSE	1 HOUR		2 HOURS		5 HOURS		16–18 HOURS		24 HOURS	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Number of intromissions................	2.2	1–4	3.5	1–8	3.0	1–6	1.4	1–2	1.2	1–2
Duration of 1st copulation (seconds)*.......	13.2	10–20	12.5	10–15	10.8	9–13	7.4	6–9	6.3	6–7
Number of pelvic thrusts on 1st intromission ending in ejaculation...........	27.2	17–35	32.5	25–40	26.8	23–31	17.8	15–20	14.8	10–20
Number of ejaculations.	1.3	1–2	1.5	1–2	2.0	1–3	1.2	1–2	1.2	1–2
Duration of erection of penis (minutes)......	10	0	10	0	10	0	4.8	4–5	3.2	1–4

* This is the time elapsing from penetration to ejaculation.

ejaculation, the number of pelvic thrusts made by the male during each copulation, the number of ejaculations achieved during the period, and the persistence of erection of the penis. The mating periods were 10 minutes in length unless some unusual occurrence, such as a fight, made it necessary to terminate a period before that time.

Table 8 summarizes the data secured from the 28 matings for Velt, from 1 hour to 24 hours after the morning injection. The range as well as the mean of each entry is given.

Examination of this table reveals some striking relationships between various aspects of the mating situation and the time elapsed since the last dose. In general, the data show that sex desire, continued eagerness to copulate, and adequacy of the sex act, were considerably greater in the hours just following a morphine injection than they were 16 to 24 hours after a dose. This generalization is supported by several aspects of the data.
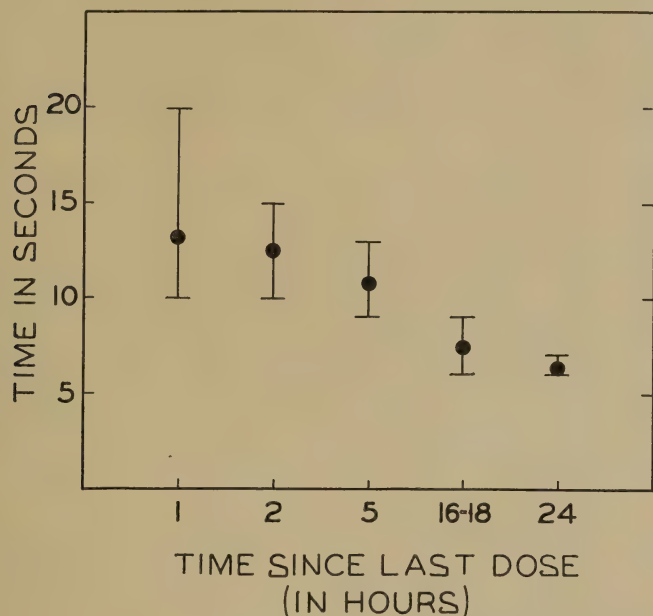
Fig. 11. Showing the duration of copulations as a function of the time elapsing since the last morphine injection. The mean time and the range are indicated for each period. Subject: Velt. (Data taken from table 8.)

First of all, the mean frequency of intromissions is less for the later periods and the range not nearly so great. Erection of the penis was maintained without exception throughout the entire 10 minutes of the early periods, whereas during the two later periods, it subsided relatively rapidly after copulation had occurred. The frequency of matings in which more than one ejaculation occurred during the 10-minute period was greater for the early periods than for the two later ones.

The data also reveal a striking change in the excitability of the

ejaculation reflex as a function of the recency of the last morphine injection. These data have also been presented graphically in figure 11. For the six matings which occurred 1 hour after ejaculation the mean duration of the first copulation was 13.2 seconds, with a range of 10–20 seconds. The mean value decreases progressively, but not greatly, for the 2 and the 5-hour periods, and is significantly less for the 16–18 and the 24-hour periods, the latter having a mean value of 6.3 seconds. The time required to achieve ejaculation during these later periods is highly uniform, also, as shown by a range of 6–9 seconds for the 16–18 hour period, and a range of only 6–7 seconds for the 24-hour period.

Corroborating the time measurements, the record of the number of pelvic thrusts required to achieve ejaculation also shows a definite hyperexcitability of the ejaculation reflex after the animal has been without a morphine injection for 16–18 hours or longer; or, to put it the opposite way, one can state the results in terms of the morphine's acting as a depressant on the ejaculation reflex, raising its threshold above the usual value, and thus making a longer period of time and/or a greater number of pelvic thrusts necessary in order to achieve ejaculation during those periods shortly after an injection had been given.

That the difference should probably be described as a depressant effect following the morphine dose is indicated by some recent data presented by Yerkes (1939). As a result of a large number of matings of three adult male chimpanzees with six females it was found that the average durations of copulation for the three male subjects were as follows: Bokar, 9.8 seconds; Pan, 8.0 seconds; and Jack, 6.7 seconds. In the light of these figures, it would seem that Velt's durations of copulation for the 16–18 hour and the 24-hour periods were about "normal," while the values for the 1, 2, and 5-hour periods were abnormally long, indicating that the morphine operated to raise the threshold of the ejaculation reflex.

As further evidence of the difference between behavior exhibited by Velt during those mating periods which followed soon after an injection and those which occurred after a consider-

able amount of time had elapsed, a condensation of two fairly typical records and protocols is herewith offered:

March 9, 1937. 11 a.m. 2 hours after morphine injection (9 a.m.). When the door between the two cages was opened Mamo (the female) came through to Velt and immediately presented. He entered at once and copulated with her; 36 pelvic thrusts and 12 seconds were required to achieve ejaculation. During the 2d minute copulation occurred again; it lasted 18 seconds and there were 53 pelvic thrusts, but no behavioral evidence of ejaculation. During the 3d minute still another copulation occurred; it lasted 20 seconds and there were 48 pelvic thrusts, ending in ejaculation. The female then groomed Velt for 3 minutes. The last 5 minutes of the period were spent by Velt in picking and scratching at his wrists and legs. He retained a full, vigorous erection throughout the 10-minute period.

March 8, 1937. 9:40 a.m. 24 hours since last morphine injection. The female (Mamo) came through to Velt when the door was opened. He had an erection and she immediately presented. Copulation occurred at once; there were 14 thrusts, lasting 6 seconds, and terminating in ejaculation. His erection began to subside during the 3d minute, and was absent during the remainder of the 10-minute period. Mamo pushed against Velt's abdomen frequently, playing and presenting. He seemed to dislike it, grimacing and whimpering when she was insistent. During the 4th minute he covered her for about 3 seconds when she presented, but there was no erection nor any pelvic thrusts. Velt paced restlessly about the cage, and then sat near the door, watching the experimenter. At the end of the period there was a brief fight between the two animals. Mamo teased Velt, he screamed and struck at her, then retired to a corner, had a short temper tantrum, which ended in choking and retching.

These excerpts illustrate many of the typical differences between the mating periods occurring soon after injection and those taking place when Velt needed a morphine dose. Not only was sexual interest stronger and more continuous under the former condition, but he was friendlier and much more apt to engage in mutual examination and grooming with the female. When needing a dose, however, sex interest would usually disappear very soon after copulation occurred, and Velt would spend the rest of the period pacing about the cage or sitting quietly huddled

in a corner. At such times he definitely resented playful or sexual overtures from the female and would withdraw from them. Occasionally, as in the illustration above, the persistence of the female would cause Velt to turn on her and fight briefly and rather clumsily. Usually, however, his response to such a situation was to withdraw, grimacing and whimpering.

The data so far presented refer to mating observations in which successful copulations occurred. In addition to these observations, there were instances in which copulation was incomplete (an intromission but no ejaculation) or in which no sexual contact was made at all, even though the female was sexually receptive and solicited sexual contacts as strongly as during other, successful, periods. These incomplete or "refusal" periods are seen to bear a definite relationship to the time elapsing since the last morphine injection. First of all, there were no refusals or incomplete copulations for any of the mating periods at 1, 2, or 5 hours after injection. One or more complete copulations occurred on all such occasions.

For the 16–18 hour period, in addition to the five complete copulations which have been reported above, there was one instance of partial copulation and two refusals. For the 24-hour period, we have the six complete copulations reported above, and also one partial copulation and four refusals. Three of these five unsuccessful periods were characterized by fights, whereas there had been no fights during any of the matings at 1, 2, and 5 hours, and one brief fight for the 16–18 hour period. These fights may have been due in part to the frustration of the receptive female at finding Velt sexually unready and unwilling. Probably a more relevant factor was the irritability and "short temper" which Velt exhibited toward other animals when needing a morphine dose, and which were conspicuous during withdrawal periods.

Two of the mating opportunities presented during the latter part of 48-hour withdrawal periods are described briefly:

September 24, 1936. 3 p.m. 48 hours since last dose. Velt had no erection when placed in the cage next to Mamo's. She presented to him against the wire mesh several times, and was definitely sexually

excited. When the door was opened, Velt came through. Mamo presented and waited, crouched, for him to mount her. He came, but instead of mounting and copulating, he fell on her, kicking, biting, flailing, and screaming. The attack was a complete surprise to Mamo, and Velt got in several blows before she broke loose and fled, screaming. He pursued her clumsily, but she easily kept out of reach. After about 5 minutes she allowed him to approach. She presented and he sniffed her genitalia, then mounted and made two or three pelvic thrusts, but he had no erection. He was eager to be taken from the cage at the end of the period.

March 8, 1937. 4:25 p.m. 30 hours since last dose. Velt had an erection when put into the cage next to Mamo's, but it subsided before the connecting door was opened. She came through and presented to him. He cried as she did so, but did not move. She paced about, ignoring him, and he remained quietly on the ledge. Later he panted rather excitedly at her, as she presented to him. No erection during the time they were together.

No copulations occurred at such times; when suffering withdrawal distress, Velt exhibited practically no sexual interests.

That an injection *per se*, and not simply the physiological effects of the drug in the blood stream, could markedly affect his willingness and ability to copulate is shown by the following two observations:

April 19, 1937. 9:30 a.m. 23 hours since last dose. Velt had no erection when put in the cage next to Bentia's. She came through to him and presented, but he paid little or no attention to her. He paced restlessly about the cage, and was eager to be removed at the end of the period. Immediately on removal he was taken to the injection room, and was given an injection of physiological saline solution. He was very eager to receive the injection. Within 2 minutes after the injection had been made, he began to have an erection. He was taken at once to Bentia and a second mating opportunity given. He had a strong erection when they came together, and copulated eagerly with her, achieving an ejaculation in $6\frac{1}{2}$ seconds. His erection disappeared during the 4th minute after copulation, and was absent during the rest of the period.

April 22, 1937. 9:20 a.m. 24 hours since last dose. Velt had no erection when put in with Bentia. She presented to him persistently.

He cried, then presented to her. She held him briefly, then turned away. Velt was taken from the cage and led directly to the injection room, where he was given an injection of physiological saline solution. After a 2–3 minute wait, he was brought back to Bentia's cage. He had an erection as he approached the cage and, when put in with her, he copulated immediately, achieving an ejaculation in 6 seconds. His erection subsided shortly, and was absent after the 4th minute.

The fact that seeing a syringe and having a hypodermic needle thrust into his skin could produce such a marked change in sexual interest and behavior is extremely interesting. The mechanics of injection *per se* had apparently acquired the capacity to relieve, at least temporarily, those aspects of withdrawal distress which kept him from copulating with the female before the saline injections were made. It is well known that human morphine addicts can often obtain temporary relief from withdrawal pangs by pricking themselves with an empty hypodermic syringe. Velt's behavior in these two mating situations illustrates the same sort of phenomenon, the syringe and injection as such acting as conditioned stimuli to produce temporarily the effects which customarily had followed them.

These observations of various aspects of mating behavior show clearly that Velt's interest and ability with regard to mating became less as the effects of morphine wore off. For several hours following an injection, opportunities to copulate would be accepted readily, and frequently more than one complete copulation would be achieved during a 10-minute period. With the onset of need for another dose, however (as indicated by the appearance of withdrawal symptoms), the chances of his copulating diminished markedly. If copulation did occur at such times, it was brief and followed at once by detumescence and lack of sex interest. Crying, and even fighting, were apt to be his responses to persistent sexual solicitations on the part of the female. When he was suffering acute withdrawal distress, copulation never occurred.

(4) Effects on auto-erotic behavior. Auto-erotic behavior in chimpanzees is not an uncommon phenomenon. The record files of these laboratories contain a number of observations of such behavior, for both male and female animals. So far as the

writer is aware, observations of self-induced orgasm in the female chimpanzee are lacking. Self-induced ejaculation among the males, however, has frequently been observed, both among the adult animals used as breeders for the laboratory colony, and among the late adolescents. Consummation is usually achieved by manual or labial manipulation of the penis, although brief, or preliminary, masturbation may employ a variety of means.

Although auto-erotic behavior had been reported for Velt occasionally during his last year in New Haven, no observations of such behavior terminating in ejaculation were observed for several months after his transfer to Orange Park at the end of October, 1935. The first observations of this kind were made in November, 1936, some nine months after morphine injections had been begun, and about three months after Velt had begun to copulate successfully with receptive females.

The regular appearance of erections in the male drug addiction subjects shortly after injections has been reported above, as well as their absence during periods of withdrawal from the drug.

On November 3, 1936, a strong erection was observed to appear quickly in Velt when he climbed up on the box-like table on which he regularly received his injection. It had been absent when he was taken from his cage. Within 20 seconds of the termination of the injection, he bent down, took his penis in his lips, and masturbated until ejaculation was produced. Some tension still persisted, as the erection was maintained, and a few minutes later he repeated the process. This behavior was duplicated on each of the following two mornings, the masturbation coming almost immediately after injection.

From this time on, to the end of the experiment, Velt frequently masturbated to ejaculation soon after the morning morphine injection was given. There were periods in which such behavior was practically a daily occurrence, and other periods during which it might occur only once a week, or even less. Not infrequently, an ejaculation achieved within the first minute after injection was made would be followed by another, toward the end of the 10-minute period that Velt was usually kept on the box on which injections were made.

Auto-erotic behavior was exhibited not only following the

injections made in the regular injection room, but also during several of the choice-tests, which have been described in an earlier section. There were 48 of these choice-tests (two series of 24 each); of these one half, or 24, were trials in which Velt needed a morphine dose, i.e., had been 16–18 hours or more without an injection. The notes record that on 8 occasions Velt masturbated to ejaculation during a choice-test session; 7 were on trials when he needed a morphine dose, and occurred shortly after injection had been made; one was on a trial when he had recently been injected. Thus, auto-erotic behavior during the choice-tests was definitely associated with the injection.

There is considerable evidence, both from instances of auto-erotic behavior in the injection room following the regular morning injection as well as during the choice-tests, that the injection situation, including the presence of the white box and its white stick-key, came to have considerable erotic significance for Velt, and to acquire the capacity to precipitate auto-erotic behavior. The frequency with which erections and masturbations appeared after injections, in many cases so very shortly after that the drug could not have begun to exert a general physiological effect, demonstrate this, as well as certain other corroborating evidence which can best be summarized by paraphrasing some observations entered in the daily records:

November 5, 1936. This morning the white (syringe-containing) box was placed in the experiment room, with the white stick-key across the room. Velt retrieved the stick-key, opened the box, and came across the experimenter's knee for the injection. After the injection he was noticed to have a vigorous erection as he sat in front of the white box. Then he stood over the morphine box, made copulatory (pelvic) thrusts toward it, and took his penis in his mouth and masturbated until ejaculation occurred. He then sat examining the box, but a few minutes later again masturbated orally.

Other observations of Velt's behavior in the experiment room during the choice-tests illustrate the phenomenon further:

December 8, 1936. (In the choice-test situation.) Velt took the white stick-key and opened the morphine box with it. He was eager

for the injection. Afterward, he was kept in the room for 10 minutes and observed from behind the screen. During this period he masturbated, by labial stimulation, five times, at least two of which were terminated by ejaculation. His erection persisted throughout.

February 13, 1937. (In the choice-test situation.) After injection Velt sat by the white box. He had a partial erection. Then he withdrew the stick-key from the box and held it close to his penis. He quickly had a vigorous erection and shortly began to masturbate; it was terminated by ejaculation.

February 26, 1937. (In the choice-test situation.) A few seconds after injection was made Velt pulled a jelled plug from his penis, showing that he must have induced an ejaculation shortly before I took him from his cage. About 2 minutes after injection he began to masturbate; no ejaculation resulted and he stopped. Then he picked up the loop of the leash (by which he is led about the grounds) and placed it over his penis, and masturbated; no ejaculation resulted. He stopped, removed the loop, then picked up the white stick-key, and rubbed it against the base of his penis while he masturbated vigorously with his lips. He soon had an ejaculation.

These observations indicate the erotic significance that the injection came to have for Velt, at times when he needed an injection and had just received one, and especially the erotic value of specific parts of the situation, such as the white syringe-containing box and the stick-key which opened it.

The brevity of the interval separating the injections and the auto-erotic behavior indicates that the injection, or injection situation, *per se*, was the cause of such behavior, rather than general physiological effects of the drug, because such effects would take longer to appear than the time which actually separated these events. Further evidence in favor of this interpretation is found in the following observation:

January 21, 1937. Velt has been masturbating immediately after the morning injection, for several days in succession. This morning, at 9 o'clock, he was given an injection of physiological saline solution in place of his regular morphine injection. Velt scratched at the injection site. He had an erection, and about 2½ minutes after the injection he masturbated and achieved an ejaculation. Again, about 6 minutes after the injection, he did so again, and had a second ejaculation.

It would thus seem that certain factors in the injection situation, rather than any effect of the drug as such, precipitated the auto-erotic behavior.

Frank, the other sexually mature male subject, had occasionally been observed to engage in masturbation before the morphine experiment was begun, but such behavior was not frequent. On May 25, 1937, about 5 minutes after receiving his first morphine injection (2 mg. per kg. of body weight), Frank was observed to have a vigorous erection; he then masturbated until ejaculation occurred. Auto-erotic behavior shortly after morphine injection became more frequent, as the following observations suggest:

June 10, 1937. Injection made at 9:15 a.m. A half-hour after injection Frank was taken to the experiment room for delayed-response tests. Immediately on being placed in the room, he masturbated and achieved an ejaculation.

June 21, 1937. Frank masturbated briefly immediately after injection this morning, but not to ejaculation. He had a vigorous erection which appeared shortly after injection, and remained for a few minutes, then subsided.

July 1, 1937. A 48-hour withdrawal period for Frank ended at 3:30 p.m. He was much excited when brought to the injection room, and there were some indications that he desired the injection. He masturbated very briefly when first brought into the injection room. He had a vigorous erection. Soon after the injection he masturbated to ejaculation. His erection persisted, and he again masturbated to ejaculation about 10 minutes after the injection.

As indicated earlier, Frank received his last morphine injection on July 12, 1937, thus his morphine experience lasted only six weeks. On the basis of the evidence presented here it seems justifiable to assume that he, too, would have come in time to show the marked auto-eroticism following morphine that Velt had done. All the indications point to such a conclusion.

Lyn, the third male subject, regularly exhibited erections of the penis following injections of morphine, but there was no clear evidence of increased masturbation at such times for him. Since he was not sexually mature and had never been observed to have

an ejaculation, this discrepancy with the results for Frank and Velt is not surprising.

Kambi, the female subject, was observed for signs of increased sexual excitability following injections, especially after she had become dependent on the drug. There was no evidence, however, to show that an increased excitability, or a greater amount of clitoris stimulation, was produced by the drug.

(5) General comment. These effects produced by morphinism on the sexual functions of chimpanzees do not agree with the results reported from experiments on monkeys. Both Kolb and DuMez (1931) and Seevers (1936a) found that morphine was sexually depressing, whereas withdrawal produced marked sexual excitability in their monkeys.

Observation of post-injection auto-erotic behavior in Velt and Frank, as well as Velt's greater willingness and ability to copulate during the first few hours after an injection than later, are also in striking contrast to the usual results reported for human subjects, addicts as well as non-addicts. For man, the consensus of available observations seems to point to morphine as exerting an anaphrodisiac effect. For chimpanzee, the results of observations of mating and of auto-erotic behavior, compel the conclusion that morphine acts as a sexual excitant, producing erections in the male, a greater adequacy and interest in copulation, and a marked increase in self-induced ejaculations, which occur most frequently shortly after the morning injection.

Just why man and chimpanzee should exhibit this marked diversity in effect of the drug is not at all clear, either from the observations of the chimpanzee subjects, or from study of the human clinical cases that are reported in the literature. What proportion of the difference is to be assigned to differences in the pharmacological effect of the drug on the two species, and what proportion to the various cultural accretions that are peculiar to the human addicts (especially those having to do with the sex mores and to feelings of sex prestige or inferiority) is a problem whose answer has not been indicated by the data of the present investigation. It is to be hoped that more detailed and exact knowledge of the sexual habits and behavior of human morphine

addicts will soon be made available, either by intensive clinical and interview techniques or (possibly) even by experimental procedures. The findings should have considerable value, not only for comparative purposes, but as a means of throwing further light on some of the personality characteristics, emotional conflicts, feelings of inferiority, etc., in the human addict.

6. The effects of partial and complete withdrawal of morphine from addicted chimpanzees

a. Forty to forty-eight hour withdrawal periods. At intervals throughout the investigation periods of forced abstinence from the drug were imposed on the subjects. The periods were of approximately 48 hours duration, this time being chosen as the probably optimal period for partial withdrawals. Observations reported by Light et al. (1929) and others for human addicts indicate that abstinence symptoms reach their maximum severity by that time, and also (and this is an important factor) that relatively little tolerance to the drug has been lost at that point. If longer partial withdrawal periods are used, little is added to the picture presented at 48 hours; moreover, tolerance is lost rather rapidly after this time, changing to a sensitization, and the resuming doses have to be made very small and increased with caution, in order to avoid toxic effects.

Table 9 summarizes the two-day withdrawal periods given to each of the subjects used in the investigation and shows the length of time that the animal had been given the drug, the dose level at the time of withdrawal, and the length of the withdrawal period in hours. In addition to the withdrawal periods summarized in this table, it should be remembered that the subjects experienced a brief withdrawal period of 22–23 hours each weekend, between the Sunday morning injection and the Monday morning injection. These short weekly withdrawals provided an opportunity to check regularly the progress of dependence on the drug and signs of addiction. Also, occasionally, a single dose was omitted at other times, thus providing additional 24-hour abstinence periods.

In an earlier section of this report there has been described the

first signs of withdrawal which appeared on Monday mornings and at other times when a dose was skipped. These served to mark the onset of physiological dependence on the drug, and were described in that connection (pp. 53–59). Descriptions have also been given earlier in this report (pp. 59–67) of the early signs of desire for the morphine injection, which were first observed during brief withdrawal periods. The purpose

TABLE 9

Showing the number and some of the data relating to the 40–48 hour withdrawal periods for the four morphine addiction subjects*

LYN				VELT			
Date	Length of time on the drug	Length of with-drawal	Dose level	Date	Length of time on the drug	Length of with-drawal	Dose level
	months	*hours*	*mg. per kg.*		*months*	*hours*	*mg. per kg.*
4/13/36	$1\frac{1}{4}$	$47\frac{1}{2}$	1.0	4/19/36	$1\frac{1}{2}$	$47\frac{1}{2}$	1.0
5/17/36	$2\frac{1}{2}$	$48\frac{1}{2}$	2.0	5/24/36	$2\frac{3}{4}$	48	2.0
7/30/36	$4\frac{3}{4}$	41	2.0	7/30/36	$4\frac{3}{4}$	41	2.0
8/ 6/36	5	40	2.0	8/ 6/36	5	41	2.0
8/13/36	$5\frac{1}{4}$	42	2.0	8/13/36	$5\frac{1}{4}$	$42\frac{1}{2}$	2.0
8/21/36	$5\frac{1}{2}$	41	2.0	8/21/36	$5\frac{1}{2}$	43	2.0
9/23/36	$6\frac{1}{2}$	$49\frac{1}{2}$	2.0	9/23/36	$6\frac{1}{2}$	$49\frac{1}{2}$	2.0
				11/11/36	$8\frac{1}{4}$	48	3.0
				1/ 6/37	10	48	3.0
KAMBI				FRANK			
5/20/37	$1\frac{1}{2}$	$47\frac{1}{2}$	2.0	6/30/37	1	$47\frac{1}{2}$	2.0
6/25/37	$2\frac{3}{4}$	47	3.0				

* In addition to the withdrawal periods described here, there were many shorter ones, of 20–24 hours duration, as explained in the text.

of the present section is to describe the principal effects of the several longer (40–48 hour) withdrawal periods that were introduced from time to time, in order to compare the severity of symptoms at different stages of the investigation, as well as to determine what changes characterize chimpanzee subjects during withdrawal from morphine.

(1) General behavior. The frequent deep prolonged yawnings which have been described earlier characterized all the with-

drawal periods and proved to be one of the most regular behavioral items in the withdrawal syndrome. Another regular
feature was a combination of restlessness and lethargy during
these withdrawals. The animal would frequently lie stretched
out on the cage floor, relaxed, as if trying to doze, but would
move his limbs about restlessly, as if unable to make himself
comfortable. Toward the end of several withdrawal periods,
however, subjects were discovered in a deep sleep during the
daytime. It is unusual for a chimpanzee to be in deep sleep
during daylight hours, and even more unusual for a human to be
able to approach the cage without waking the animal. Yet for
all three addicted subjects—Lyn, Velt, and Kambi—this phenomenon occurred. The experimenter was able to come to the
side of the cage and stand watching the animal, or even to enter
the cage, without awakening him. In fact, it sometimes took
several utterances of the animal's name to arouse him, whereupon
he would awake suddenly with a start and cry on seeing the
experimenter. This seems to be very close to the behavior that
Light (1929) and others have described for human addicts during
withdrawal, and is usually called by addicts a "yen sleep."

During withdrawal periods the subjects exhibited a marked
irritability, as shown by increased resistance to being handled
and often an active resentment of procedures which ordinarily
provoked no resistance. It was also shown by an increased
unfriendliness and antagonism to other animals. Two excerpts
from the protocols will illustrate these statements:

July 31, 1936. 3:15 p.m. Lyn and Velt have had no morphine for
about 24 hours. Lyn was put into Velt's cage for observation of the
social relations between them. They paced about quietly when put
together, paying little attention to each other; no playing or wrestling
as on other occasions. After about 5 minutes, Lyn obtained a long
grass stalk, and was manipulating and chewing it, while seated on the
cage floor. Velt came to watch him and sat with his face close to Lyn's.
In handling the stalk, it happened that Lyn caused the end of it to
swing about and strike Velt mildly on the face. Velt at once became
very angry. He screamed and seized Lyn's arm, shaking it and trying
to bite it. Both animals rolled on the floor, kicking, biting, and scream-

ing. Then they suddenly separated and quieted down at once. Soon they were sitting quietly close to each other. This "flare-up" was highly unusual for these two animals.

September 24, 1936. 2 p.m. Lyn and Velt have had no morphine for 47 hours. Both were unfriendly and unsociable this afternoon. Velt was unusually irritable. He even tried to snap at my finger as I was examining him through the wire mesh of the cage wall. Lyn was put in Velt's cage for a few minutes, for observation of social relationships. Velt at once attacked him, screaming, and they both rolled on the floor, fighting and screaming. Then they separated suddenly, and both paced quietly about the cage; at times they sat quietly close together.

It was only a few minutes after this latter incident that Velt was taken from his cage to mate with a female chimpanzee, and, instead of copulating with her, attacked her savagely as described above (p. 95). Other attacks on female animals intended as sexual partners have also been described for Velt. He seemed to exhibit a greater amount of irritability toward other animals during withdrawal periods than the other subjects did, but they also definitely displayed it. Kambi, for example, would sometimes attempt to attack other animals through the wire mesh of their cage walls, as she was being led by on leash.

Kambi and Lyn also objected strongly to the taking of rectal temperatures during the periods of withdrawal. Ordinarily they coöperated in this measurement satisfactorily, but at measurements attempted during withdrawal periods they would grimace and pull away, as if the thermometer were causing them discomfort even though it was well lubricated with vaseline or K-Y jelly.

Resistance to being returned to the living cage during a withdrawal period, without being given a morphine injection, as well as signs of frustration if the experimenter approached the cage at such times and then departed without taking the animal with him, became progressively more marked as the investigation proceeded. After the animals had become genuinely addicted to the drug, as shown by evidences of the desire for the injection, the experimenter regularly had difficulty in getting them back

into their living cages without giving them an injection, during the latter part of a 48-hour withdrawal period. He frequently was forced to employ a good deal of ingenuity and subterfuge to accomplish this end. Screaming and temper tantrums often accompanied the animal's resistance to being returned to its cage; Kambi sometimes attacked the leash and bit it savagely. None of the subjects actually attacked the experimenter at such times, but it frequently seemed as if a little more "pressure" from him might provoke it.

During the latter part of the investigation this resistance became so great that on two or three occasions the experimenter was forced to give the animal an injection of physiological saline solution (in order not to terminate the withdrawal period prematurely) and then hurry him into his cage before he discovered the trick.

January 28, 1937. (Withdrawal period.) Velt whimpered and cried and resisted my efforts to return him to his cage; he tugged at the leash and tried to lead me to the injection room. I tried for 5–10 minutes to get him in his cage, but he refused to go; he screamed loudly and had a temper tantrum at one point. Finally I capitulated and led him to the injection room. He strode along ahead of me, panting eagerly, and tugged me into the injection room; he jumped up on the box, much excited. I gave him a small dose of saline solution (1 cc.) and he immediately became quieter, and even began to pick at his wrist a little. I put him back in his cage about 2 minutes after the dose (i.e., well before a morphine dose would begin to have any general effect). He went perfectly willingly, in marked contrast to his behavior a few minutes earlier. When I returned later, however, he cried loudly to be taken from the cage.

These incidents indicate that the injection *per se* came to have a brief sedative effect on the morphine-needing subject, and would alleviate, at least temporarily, the withdrawal symptoms.

The picking and scratching following the saline injection were obviously a conditioning phenomenon, resulting from the fact of having received an injection, since such injections (with morphine) had so regularly induced this behavior in the past.

Another conditioned effect of the injection *per se* has already

been described above (pp. 95–96) for Velt in the mating situation, in which a small saline injection markedly increased his willingness to copulate.

(2) Physiological functions. The withdrawal syndrome regularly included several changes in physiological functions, some of which have been mentioned already in this report. Many of the changes seemed to be indicative of a sympathetic hyper-irritability. Hyper-salivation, indicated by the animal's manipulating saliva in his mouth, depositing it in his hand or on the cage floor and licking it up again, was common; so was lacrimation and rhinorrhea. Brief, coarse tremors of the lower limbs were occasionally noted during the later hours of withdrawal periods.

Gastro-intestinal functions were markedly disturbed by cessation of morphine doses. Appetite diminished and, although fruit would usually be eaten promptly, other items in the diet such as crackers and raw vegetables might still be left at the next feeding time, something that was rare at other times. A 48-hour withdrawal period was always accompanied by an increase in frequency and amount of defecation. When the animals became highly dependent on the drug, withdrawal produced a marked softening of the feces, although rarely to the extent of diarrhea. Evidences of gastric irritability were also shown by considerable stomach rumbling (borborigmus), by a definite increase in regurgitation of food material, and by actual retching and vomiting if the animal was frustrated to the point of a temper tantrum.

Such diminution in intake and increase in elimination obviously involve weight loss, and the animals invariably lost weight during the withdrawal periods. The greatest amount of loss was found at the end of the withdrawal period, or during the next 24 hours. The animal would then slowly recover weight, and return to the pre-withdrawal level within 5 to 8 days.

Table 10 shows the percentage of body weight lost by the subjects during the 40-48 hour withdrawal periods. The individual as well as the mean values are fairly consistent for all four subjects. Comparing these results with observations on human addicts, it is found that the most pertinent data are those presented by Himmelsbach (1936). This investigator has shown

in graphic form (1936, p. 34) the curve of weight loss and recovery following abrupt and complete withdrawal of morphine from 10 selected addicts. His graph shows at the 2-day (48-hour) point a mean weight loss of 4 per cent, which agrees exactly with the mean weight losses of the four chimpanzee subjects. Thus despite the absolute differences in body weight between adult human beings and adolescent chimpanzees, 48 hours of abstinence seems to produce equivalent amounts of weight loss.

Metabolic rate. For Lyn and Velt the first two withdrawal periods (which came about 5 to 6 weeks after the beginning of morphine administration) resulted in a lowering of metabolic

TABLE 10

Showing the percentage weight loss produced by periods of morphine withdrawal

LYN		VELT		KAMBI		FRANK	
5/17/36	3%	4/19/36	1%	5/20/37	4%	6/30/37	3%
7/30/36	4	5/24/36	2	6/25/37	4		
8/ 6/36	5	7/30/36	5				
8/13/36	5	8/ 6/36	5				
8/21/36	3	8/13/36	4				
9/23/36	4	8/21/36	6				
		9/23/36	4				
		11/11/36	2				
		1/ 6/37	5				
Mean.......4%		4% (3.8)		4%		3%	

rate, about 10 per cent below the mean of pre-morphine measurements for Lyn, and 16 per cent for Velt. Kambi, however, at a comparable time, showed an increase of 21 per cent over her average pre-morphine rate.

Measurements on Lyn and Velt during subsequent withdrawal periods showed some increase in metabolic rate, but the restlessness exhibited at such times probably made the results spuriously high. Circumstances made it impossible to obtain further metabolism measurements on Kambi.

Nocturnal activity. Earlier in this report (p. 38–39) it was shown that a somewhat greater amount of nocturnal activity occurred when the afternoon dose was given than if it were

omitted. During the late spring, 1936, nocturnal activity of Lyn and Velt during two withdrawal periods was compared with that during periods when morphine was being administered at the usual rate. For the first withdrawal period (5 to 6 weeks after beginning morphine administration) there was no noticeable effect on nocturnal activity. For the second one (about 5 weeks later) there was a marked increase of nocturnal activity as compared with the usual rate. By this time both animals were definitely dependent on the drug. The increase in nocturnal activity may be interpreted as simply restlessness during sleep, as insomnia, or a combination of both. It corresponds to the insomnia commonly observed in human addicts during withdrawal periods.

Temperature. It was shown earlier in this report (pp. 33–35) that small doses of morphine lower the body temperature of chimpanzees, but that adaptation to this effect soon takes place. The 48-hour withdrawal periods produced a definite lowering of body temperature in Lyn and Velt, as compared with measurements made immediately before and after the withdrawals. The decreases ranged from about half a degree centigrade to over a degree. There was some evidence of adaptation, as the decreases were not as great for the September, 1936, withdrawals as they had been for the May withdrawal periods. No demonstrable temperature changes during withdrawals were observed in Kambi and Frank; the briefness of their morphine experience was probably responsible for this lack.

These results for Lyn and Velt are in agreement with the results reported by Kolb and DuMez (1931, pp. 14–16), who found that rhesus monkeys dependent on opiates suffered a marked decrease in body temperature during prolonged withdrawals. The more pronounced effect observed in their animals was very probably due to the extremely high dose level from which they were withdrawn, approximately 50–60 milligrams per kilogram of body weight, as compared with 2 milligrams per kilogram for our chimpanzee subjects.

The temperature data from chimpanzees and monkeys thus contrast with the temperature rise (fever) that is reported regu-

larly to be part of the withdrawal syndrome of the human addict (Light et al., 1929, and others) and constitutes another difference in the pharmacological effects of morphine between man and other primates.

Pulse and respiration. The withdrawal periods produced no demonstrable effect on the pulse rate. The respiration rate seemed to be considerably increased during withdrawal but part, at least, of this increase was due to the excitement (with panting, etc.) which the subjects would exhibit when the experimenter took them from the cage for examination and measurement during a withdrawal period. Hence, little weight can be attached to any of the respiration measurements secured at such times. It should be pointed out, however, that the increase in respiration rate which was noted agrees with the results reported for human addicts during certain stages of morphine withdrawal.

Blood counts. Counts of red and white blood cells were made on Lyn and Velt during several withdrawal periods. Very little change in the number of red cells was noted at any time. During the first two withdrawal periods (spring, 1936) there was some evidence of a decrease in number of white cells. Counts taken during subsequent withdrawal periods failed to substantiate this finding, however. In general, the results of the white cell counts were too variable to warrant any conclusions from them regarding the effects of the drug or withdrawal from it.

The later withdrawal periods experienced by the subjects did not seem to produce any more intense symptoms or greater distress than did earlier withdrawal periods which came after the animals had become dependent on the drug. The amount of weight loss, the diminution of appetite, and other items in the physiological syndrome of withdrawal remained fairly constant from one withdrawal to another. In short, once dependence had been established, successive withdrawal periods produced little or no progressive severity of organic effects, under the conditions employed.

The most noticeable progressive change which successive withdrawals produced was an increase in desire for the morphine injection, and in frustration when it was denied. This might be

interpreted as increasing clearness of perception of the part played by the injection in relieving withdrawal distress.

It is indeed significant that in these animals there was produced such a definite desire for the drug, on dose levels so low that the physiological upset produced by withholding the drug was not severe. The finding is not only of interest for our knowledge of primate perceptive capacities, but is suggestive with regard to dose sizes which might fruitfully be employed in work of this sort with the higher mammals.

(3) *Behavioral tests.* It was shown earlier in this report (pp. 46-51) that after morphine dependence had been established, subjects performed less accurately at times when an injection was needed than they did a half-hour after receiving an injection.

Delayed-response and multiple-choice tests made during withdrawal periods produced results consistent with this finding. Performance was consistently less accurate during periods of morphine deprivation, although the results do not satisfy the criterion of statistical reliability. The explanation of the decrement seems to lie partly in the decreased food motivation which accompanied withdrawal periods. More important, however, seem to be the heightened restlessness and distractibility during withdrawal, which undoubtedly interfere with orientation and successful retention in these two problems.

b. Complete withdrawals and return to normal. Since Lyn and Velt both died while still addicted (see below), observations on the effects of complete withdrawal of the drug are limited to the other two subjects, Kambi and Frank. Kambi received her last morphine injection at 11 a.m., July 11, 1937, beginning a complete, abrupt withdrawal, the so-called "cold turkey" treatment in addicts' jargon. She had been receiving morphine regularly for approximately $3\frac{1}{2}$ months, and was getting 3.0 milligrams of morphine per kilogram of body weight, twice daily, when withdrawal started. Frank received his last injection at 10 a.m., July 12, 1937; he had been on the drug for 6 weeks, and was getting 2.0 milligrams per kilogram twice daily. A description of the course of withdrawal and return to normal will be given for each animal.

Kambi. Within 24 hours the usual withdrawal syndrome had

appeared; it was not more severe than on previous withdrawals, nor did it become so.   Appetite was diminished for 3 days, then began to improve and by July 19 seemed to have returned to normal.   Feces became very soft and considerably increased in quantity, but began to regain their firmness by July 16 and quickly returned to normal appearance and quantity.   Kambi engaged in regurgitation and reingestion of food material fre-
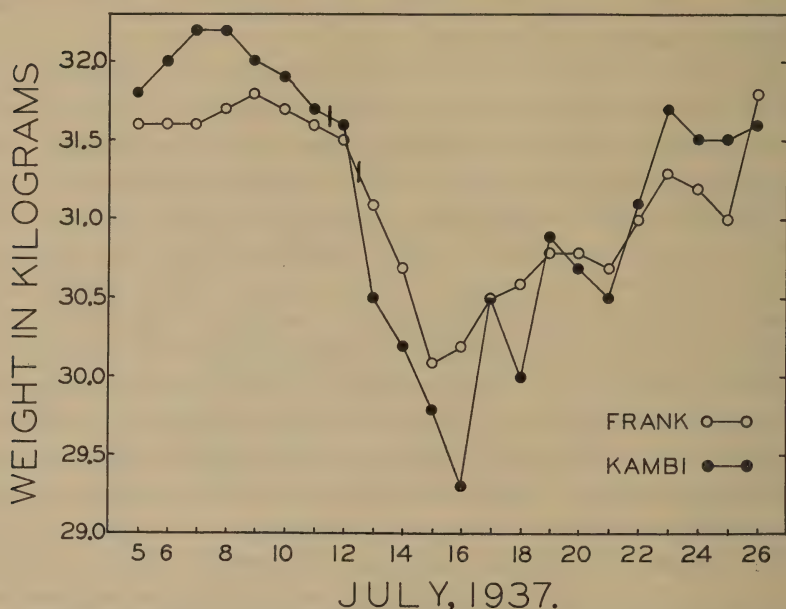

Fig. 12. Weight changes resulting from complete, abrupt withdrawal from morphine.   In each case the short vertical bars have been placed between the date of the last morphine dose and the first day of withdrawal.   Subjects: Frank and Kambi.

quently from the second to the fifth days of her withdrawal; also, borborigmus was common at this stage, indicating, together with the other symptoms, that the withdrawal was producing definite gastric disturbances.

Kambi lost weight for 5 days after morphine was cut off, then began to recover, and by July 23 had regained all the weight she had lost during the withdrawal.   Figure 12 shows the progressive weight changes for the 2 weeks following the last dose of morphine. In terms of proportional weight loss, she lost 8 per cent of her

body weight from the day of the last injection (July 11, 1937) to the lowest point (July 16). This is seen to be more than any of the subjects lost during 48-hour withdrawal periods (see table 10). Himmelsbach (1936) has found that human addicts also lose weight for 5 days after withdrawal, then gain rather rapidly after that point. The average weight loss reported by him was between 6 and 7 per cent, which is somewhat less than the amount lost by Kambi.

Kambi appeared to be "bristled up" frequently from the second to the fourth days of withdrawal, evidence that the withdrawal was stimulating pilomotor activity.

On July 20 she began to have a slight sexual swelling, the first she had exhibited since drug administration had been started. The swelling increased and within a few days had become very noticeable. This effect of morphine withdrawal has been described in detail earlier in the report (pp. 86–87).

During the first 3 days of the withdrawal Kambi was very irritable. She refused to allow the experimenter to make measurements of temperature and pulse, thus preventing the gathering of data on these functions during the most crucial period of the withdrawal. She exhibited definite signs of desiring an injection during the first 3 days, tugging at the leash to get to the injection room, resisting being returned to her living cage without being given an injection, whimpering and crying when put into her cage and seeing the experimenter depart; in short, the general behavior which had been exhibited by all three of the addicted subjects during times of morphine need.

On July 14 Kambi permitted some handling and measurements but was still relatively non-coöperative. On July 15 the experimenter entered her cage with the hypodermic syringe in hand. She grimaced and whimpered softly when she saw the syringe, and quickly came across the experimenter's knee when he took the familiar injection position. She showed but little disturbance, however, when he left without giving her an injection.

After July 17 no definite withdrawal signs were observable in Kambi. She was gaining weight and her appetite was good.

On July 25, just 2 weeks after morphine administration had

been terminated, she was taken to the injection room, following the routine which in the past had led to a morphine injection. She followed the experimenter into the injection room quietly, and climbed up on the box on which injections were made. The experimenter took the syringe from the white box and showed it to her; Kambi looked at it but was calm and quiet. There was no sign of the excitement which she and the other addicted animals had shown under such conditions near the end of 48-hour (and shorter) withdrawal periods. When the experimenter put his knee in the injection position, she came across it readily, but with no hurry or excitement. It was obviously merely the coöperation of a well-trained animal. After a few seconds the experimenter withdrew his knee, then returned the syringe to the white box without having given the animal an injection or even contact with the syringe needle. She was then led back to her living cage, and went willingly and quietly, without any signs of frustration or resistance.

It is clear from this incident that Kambi, in the 2 weeks that had elapsed since her last injection, had lost her addiction. By that is meant that she no longer exhibited any sign of desiring a morphine injection. This desire had become well-developed during the course of the investigation and had been very strong toward the end of the 48-hour withdrawal periods, when she was exhibiting definite withdrawal symptoms. However, withholding morphine for 2 weeks (i.e., until the withdrawal symptoms had disappeared and the animal had recovered her appetite and weight) resulted in no sign of desire for an injection when such an opportunity presented itself.

This loss of desire for the injection in such a short period of time contrasts with the strong tendency for the human addict to resume ingestion of the drug as soon as it becomes easily available. The evidence seems to indicate that for this chimpanzee subject the morphine injection was desired not as an "escape from reality" but as something which terminated withdrawal distress, and that with the disappearance of withdrawal symptoms desire for the injection also disappeared.

Frank. This animal, since he had been on the drug for only 6 weeks and was getting 2.0 mg. per kg., twice a day, was not

expected to have as acute a withdrawal as Kambi. The characteristic physiological syndrome did appear and included the items reported above for Kambi, but with considerably less intensity. Appetite was somewhat diminished for 2 days, then appeared to be normal thereafter. Feces became soft, but returned to normal in 5 days. No other withdrawal symptoms persisted longer than 5 days. Figure 12 shows that Frank lost weight for 3 days, then regained his weight gradually although it was a full 2 weeks before he recovered all the loss. At his lowest point, he had a weight loss of 4 per cent, considerably less than the loss exhibited by Kambi.

During the first 3 days of withdrawal Frank was restless and uneasy in his cage, especially when being observed. He was clearly eager to be taken from his cage, and whimpered and cried when the experimenter would depart without doing so. There was no tugging to get to the injection room, nor other indication that he desired an injection, but there was some resistance to being returned to his living cage. This indicates that Frank was just beginning the sequence which, in the other subjects, had led to realization of the function of the drug and, consequently, to addiction.

On July 25, almost 2 weeks after morphine had been withdrawn, the injection situation was presented to Frank, in the manner described above for Kambi. Frank showed no interest or excitement at sight of the syringe, but was merely quiet and coöperative. He showed no frustration at being taken from the injection room and put back in his living cage.

Frank's withdrawal demonstrated only the sequence of events that characterize the animal that has become dependent, but not markedly so, on continuing administration of morphine; there was no evidence that he had become addicted to the drug, although there were indications that if the experiment had been continued, addiction would soon appear.

7. The fate of the drug addiction subjects

Kambi. This animal, following her complete withdrawal from morphine, gained weight steadily until December, 1937, and appeared to be in satisfactory health. During the first few months

of 1938, however, her general health was reported as rather unsatisfactory, although no definite diagnosis was made. There was no evidence to indicate that her lack of good health was due to the regime of morphine administration.

According to her estimated age Kambi should have been expected to begin menstruating as early as June or July, 1937, whereas her first menstruation did not occur until July, 1938. The appearance of this indication of sexual maturity was undoubtedly delayed by the administration of morphine and later, probably, by her poor general condition.

Frank. This animal gained weight rapidly after the termination of morphine injections, increasing from 32.2 kg. on August 1, 1937 to 39.0 kg. on February 1, 1938. His general health was reported as excellent.

That the drug produced no after-sterility in Frank is indicated by the fact that he impregnated an adult female chimpanzee of the laboratory colony several months after his last injection of morphine. A normal, healthy infant was born of the union.

Lyn. On October 1, 1936, Lyn and Velt were found to have mild head colds, the principal symptom being a rather copious nasal discharge. Velt recovered fully in 4 or 5 days, but by October 5 Lyn was a very sick animal. He refused food and all fluids and appeared listless and weak. Fluids were administered rectally and the morphine injections continued. They seemed to make him more comfortable, but nevertheless he died during the night. An autopsy was performed by Doctor L. Y. Dyrenforth, pathologist, of Jacksonville, Florida, whose examination disclosed:

1. Confluent broncho-pneumonia of the left lower pulmonary lobe, with some involvement of the upper left.
2. Mucopurulent tracheobronchitis.
3. Anemia and parenchymatous degeneration of the myocardium.

It was suggested that the indications of weak heart may have rendered the animal more susceptible to the pneumonic invasion, but the fact remains that the percentage of fatalities in cases of pneumonia among captive chimpanzees is very high, even without

any other complicating factors.   Doctor Dyrenforth also stated that there had appeared no evidence that morphinism had contributed to the death of this animal.

Velt.   Velt had had three mild digestive upsets during the course of the morphine investigation, each characterized by diminished appetite, weight loss, and the appearance of watery, foul-smelling feces.   The condition in each case cleared up in 2 or 3 days and the animal appeared to be normal again.

On April 22, 1937, Velt appeared to have another of these upsets, but this time the disturbance became steadily more serious. Despite the intravenous administration of glucose solution and other medication the animal died at noon, April 26.   This autopsy was also performed by Doctor Dyrenforth.   His principal findings were:

1. An intense membranous colitis with multiple adhesions throughout the gastro-intestinal tract.   The lower half of the intestine showed multiple hemorrhages of the mucous membrane.   In the cecum there were large necrotic areas with ulcerated bases.   The ileum was similarly involved.

2. A massive infestation by intestinal parasites; namely, Strongyloides stercoralis, and Oxyuris vermicularis.

Evidently Velt's death was due to an acute colitis, caused by (or at least markedly aggravated by) a heavy parasitic infestation. Infestation by the above and by other intestinal parasites is common among captive chimpanzees, and although such infestation does not ordinarily have a fatal outcome, it may very well be contributory to otherwise unexplained cases of chronic poor health, miscarriages, etc.

Because of the sparseness and relative non-motility of sperm in samples of Velt's ejaculate (see above, pp. 87–88), histological examination of the testes was made.   An excerpt from Doctor Dyrenforth's report follows:

These histological preparations (testes) have a perfectly normal appearance and are apparently identical with those of human beings as far as we can tell.   There is no evidence under the microscope of the

presence of any factor that might be responsible for the sterility of this animal.

At autopsy the brain was removed, approximately $3\frac{1}{2}$ hours after death had ensued, and placed at once in 10 per cent formalin. It was hoped that an opportunity might be found to have a histological examination made, in order to determine whether any neural changes had occurred which could be ascribed to the chronic morphinism. Little is known about possible changes in the brain due to chronic addiction to morphine in humans, and it was felt that such a study of this chimpanzee brain might possibly have considerable value for drug addiction research in general.

Some 2 months later a young chimpanzee of the laboratory colony suffered accidental death due to strangulation, thus providing a "control" brain against which to compare changes in the brain of the morphinized animal. So far as possible conditions were made the same for the removal and preservation of the second animal's brain.

In August, 1937, the two brains were sent to the National Institute of Public Health, United States Public Health Service,[3] in whose Division of Pathology histological examination of the specimens was made. Nissl, Van Gieson, and Marchi methods were used in the preparation and examination of the material.

In the report of the examination and comparison of the two brains, which was submitted to the writer by Doctor R. D. Lillie,[4] the following statements summarize the significant findings:

1. In most essential aspects the two brains show no significant differences.

2. The fatty degeneration of corona radiata and pyramidal tracts which was found is slight in extent and degree, but apparently more

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[3] This study was made with the approval and under the direction of Doctor L. R. Thompson, Director of the National Institute of Health, and under the direct supervision of Doctor R. D. Lillie, Acting Chief of the Division of Pathology, National Institute of Health.

[4] The detailed report made on this neurological material will gladly be forwarded by the writer to any investigator who may wish to examine it.

definitely marked in ⚡12308 (the brain of the morphinized animal) than in ⚡12309 (the "control" brain). While the evidently more acid fixation may have had some influence it is thought that the difference may be significant.

In commenting briefly on these findings, it was Doctor Lillie's opinion that there was some slight degeneration of myelin sheaths in the cortical area, probably induced by the chronic morphinism, but that further studies on more extended material would be necessary to establish this definitely.

These findings, nevertheless, should prove provocative for drug addiction research in general, as they suggest that it may be possible to establish certain neural changes as underlying the phenomena of addiction and perhaps lead to a better understanding of addiction and withdrawal in general.

PART III. CONCLUSIONS AND SUMMARY

A. CONCLUSIONS

1. The nature of morphine addiction in chimpanzees

The experimental and other observational data which have been presented in this report serve to sketch in a picture of chronic morphinism as it is seen in the chimpanzee. The effects of small single doses, of chronic administration of the drug, and of withdrawal have been shown to resemble closely many of the effects reported for human morphine addicts. A comparison with results reported in the experimental literature shows that chimpanzee morphinism as reported here is definitely more human-like than is that of any other animal form that has been studied.

A question that may well concern us at this point is the problem of whether or not the condition which we have described for chimpanzees really deserves to be called addiction, in the sense in which the term is used to describe human morphinists, even granting the experimental results described above. This question is raised in view of the findings of the present investigation, and in connection with statements as to the nature of addiction which have appeared from time to time in the literature.

A point of view which has been fairly persistent is one which was early expressed by Biberfeld (1916) with regard to morphinism experiments with animals. He stated that such experiments could have no relevance for problems of addiction, but bear only on matters of the physiological action of the drug, induced tolerance, etc., etc.

This view has recently been quoted with approval and extended, by Lindesmith (1937), in a sociology doctoral dissertation. Lindesmith's position seems worthy of quotation here because of the point of view taken regarding animal experimentation in this field, and because of the "pre-judgment" of investigations such as the present one. Quotation is made from

120

several passages in which the position seems most definitely stated. Italics are those of the present writer.

Pp. 84–85. . . . we may define the object of our study as consisting in that behavior in regard to opiate drugs which is distinguished primarily by an intense self-conscious desire for the drug and by a tendency to relapse, evidently caused by the persistence, in some form, of this desire after the drug is removed. Other or correlated aspects of this behavior are the sense of dependence upon the drug as a twenty-four hour a day necessity, the impulse to increase the dosage far beyond the point of bodily necessity, and the definition of self as an addict. . . . We presume that *it will be evident from the above definition that an animal could not be called an "addict"* in the sense of the word as it has been defined, regardless of how much of an opiate drug it were to be given. It seems to us that Johannes Biberfeld has correctly expressed the relationship and bearing of animal experimentation to the problem of drug addiction when he asserted that addiction involved two types of phenomena—tolerance for morphine, and craving for morphine—and that it was only the former which has any connection whatever with animal experimentation. The craving, he felt, was a phenomenon of an entirely different character and, so to speak, on a different level, so that animal phenomena could not shed any illumination upon it. *Certainly from the point of view of social science it would be ridiculous to include animals and humans together in the concept of addiction.* For precisely the same reasons it seems evident that infants cannot be included in the concept of addiction, regardless of how long they may be given opiates.

P. 204. The belief that withdrawal symptoms are caused by the absence of the drug is a social belief which has been built up and elaborated gradually in the history of the race. Each individual addict does not rediscover this knowledge for himself but rather has it thrust upon him by his social environment,[1] for it is present in many parts of our culture . . . (Footnote:)[1] We have never encountered an addict who did not have some knowledge of beliefs concerning addiction prior to becoming an addict, although the hypothetical possibility of rediscovering the belief that withdrawal distress is due to the withdrawal of opiates, etc., by trial and error must be admitted, since that was no doubt the manner in which the interpretation was first built up. It must be emphasized, however, that this interpretation as a result of trial and error processes, or any interpretation, presupposes the existence

of a culture which supplies the categories and the language in terms of which the interpretation is made. *Neither a feral man nor a chimpanzee could be expected to achieve this interpretation of withdrawal distress, regardless of any experiences they might have with the drug.*

P. 208. We may thus say that, taking into account the fact that animals, infants, idiots and the insane, as well as normal people, may have the drug administered to them regularly without their knowledge, *only those to whom the drug's effects can be explained can become addicts.* ... The immunity of the insane, of animals, of idiots and of young children is based upon the feature common to all that the withdrawal symptoms cannot be satisfactorily explained to them.

P. 220. The social factors are therefore not incidental to addiction but central. The phenomenon of opiate addiction is neither physiological nor psychological in essence—it is social through and through. If there were no organized social life there would be no addiction, *and addiction itself does not and cannot exist outside of human society.*

If the conclusion that has been made from the data of the present investigation is valid, namely that a genuine addiction to morphine has been unambiguously demonstrated in chimpanzee subjects, then such factual material necessarily forces at least a modification of the theoretical position and the predictions therefrom as set forth by Lindesmith. The subjects of the present investigation did not have the nature of morphine addiction "explained" to them; nor did it appear in them as a "social phenomenon" in the sense in which Lindesmith has used the term.

The appearance of addiction in these animals involved essentially the formation of an association between the hypodermic injection and the alleviation of withdrawal symptoms. That the association was actually learned has been, in the writer's opinion, amply demonstrated; it is his contention that this association, and not anything "social" (in the sense of societal) is the essence of morphine addiction. Theories of the nature of drug addiction based upon the belief that a chimpanzee or other infrahuman organism could not independently discover (i.e., by "trial and error") the association between injection and relief of withdrawal symptoms must be revised in the light of the present

data. The demonstration of chimpanzee addiction is crucial for Lindesmith's central thesis as to the essentially societal nature of addiction.

It should readily be granted, as Lindesmith maintains, that the "social phenomenon" factors are important in the etiology of human drug addiction.   But the fact that chimpanzees become addicted to morphine indicates that these factors are not indispensable.   Morphine addiction seems to be fundamentally a phenomenon of learning or perception, which may or may not be socially facilitated.

It should be pointed out, however, that there is at least one sense in which the subjects of the present study were not shown to be addicted in the full sense of the definition ordinarily used, and as formulated by Lindesmith (1937, p. 84).   This concerns the tendency to relapse into use of the drug following a complete withdrawal or "cure," which is so characteristic of human addicts.

In the present study the one case of complete withdrawal of morphine from an addicted animal (Kambi) showed no evidence of interest in, or desire for, the injection two weeks after cessation of the drug and after the withdrawal symptoms had disappeared. It is obvious, however, that our evidence is far too limited to justify any assertion that addicted and "cured" chimpanzees would not exhibit any tendency to seek readdiction.   This one case was relatively lightly and briefly addicted and opportunity for readdiction was merely an informal presentation of the injection situation.   It might well be that conditions could have been established (perhaps involving frustrations or other psychic stresses) which would have led the animal to evince a desire for the reëstablishment of morphine administration, as an "escape" from an unpleasant environment.

A valuable extension of the present study would be the induction of morphine addiction in one or more chimpanzees and then a sequence of complete withdrawals from the drug, followed in each case, after an appropriate interval, by readdiction.   Such a program, especially if the animals were subjected systematically to various traumatic experiences and frustrations following each

withdrawal, might produce a "tendency to relapse" into morphine addiction when the opportunity to do so was made available. If such results were secured they would have considerable significance for drug addiction theory in general.

The data of this study indicate that a possible euphoria produced by the drug played little, if any, part in the induction of these addictions. The initial doses were so small and the increases in dose size so gradual that tolerance to addicting doses was acquired without the subject's experiencing any definite sedation (with which the euphoria is associated in man) from them. We obviously did not possess any technique for detecting or measuring euphoria in chimpanzees, but the conditions of the experiment, in the light of human addictions, seem to justify the assumption that it was probably not a factor in the present cases.

The addiction of chimpanzees to morphine thus appears not to be an attempt to recapture pleasurable states which were previously induced by injections, but rather an attempt to alleviate the symptoms produced by the delay or omission of the regular injection. Clinical evidence indicates that this condition is usually the case in human addictions. The period of euphoria from the drug is relatively short, but the drug must be continued to keep the individual feeling "normal," i.e., to keep warding off the distressing withdrawal effects. Any "pleasure" in morphine addiction then is at best a negative sort of thing—the prevention of, or escape from, the pangs created by absence of the drug.

This study also contains implications for those theories of drug addiction which have maintained that the genesis of human morphine addiction is to be sought primarily in predisposing personality factors—emotional instability, conflicts, depressions, etc.—and that morphine use and subsequent addiction are essentially an "escape" from the harsh realities of life. Such a view is often used to explain the fact that therapeutic administration of morphine induces addiction in some persons and not in others.

To show that chimpanzees can become addicted to morphine is to provide additional evidence that this view is not adequate as an exclusive explanation of addiction. These animals were presumably not neurotic or unstable, and did not take the drug

in order to escape from reality; yet they became addicted. It is not intended by this argument to minimize the importance of predisposing personality factors in the etiology of many human addictions, but rather to urge that this cause appears in the light of the present evidence not to be an absolutely essential one. Kolb (1925) and others have shown that personality defects are frequently, although not invariably, predisposing factors in addiction; the present study presents further evidence that addiction can be induced in the absence of such predisposing (human social) factors.

Morphine addiction then is not necessarily dependent on personality defect nor on social knowledge of the drug and its effects. It is not simply a neurosis. This study has added further corroboration, if such were needed, to the view that addiction has a firm organic basis (whatever future research may reveal its exact nature to be) and that the withdrawal symptoms are essentially physiological symptoms. The older view that withdrawal symptoms were a "play for sympathy" on the part of the addict in order to win him another dose, has been pretty well abandoned in present day thinking, although it is beyond question that the human addict can control the severity of the symptoms to a considerable extent, if it seems advantageous to do so. The similarity of the withdrawal syndrome in chimpanzee and man strengthens the view that the symptoms are predominantly physiological and involuntarily produced.

Drug addiction, whether in the human or the chimpanzee subject, can be considered as a state of equilibrium, the departure from which creates a condition that generates powerful motivations to restore that equilibrium—motivations that pervade the behavior of the organism and predominate over other, normally primary, desires.

2. The value of infrahuman primates in drug addiction research

The employment of chimpanzee subjects in this investigation has made it possible to narrow considerably the gap which hitherto existed between the nature of chronic morphinism in human and in infrahuman forms. Prior to this investigation morphine

addiction had not been established for any infrahuman organism, and the statements of Biberfeld (1916), Plant and Pierce (1928), Lindesmith (1937), and others regarding the essential differences between morphinism in man and all other animals seemed to be valid. Even studies using the rhesus monkey as subject had not succeeded in narrowing this gap significantly.

The use of chimpanzees in a morphinism investigation has provided an experimental organism whose behavioral capacities have been shown to resemble those of humans more closely than any other laboratory animal. Also, and this is a highly important factor, it is an organism which can be trained to a high degree of intelligent coöperation in many experimental procedures, and also to the use of symbolic rewards of various sorts.

Since morphine addiction seems to depend essentially upon forming an association between the administration of the drug and the alleviation of withdrawal symptoms, and since this sequence involves a time lag of 10–15 minutes or more, the value of using subjects high enough in the phyletic scale to be able to make a delayed association of this nature is obvious. By this token, animals such as the rat, for example, could probably never become addicted to morphine, simply because they are not capable of forming associations of this order.

There still remains the question of why monkeys have not become genuinely addicted to morphine in studies in which they have served as subjects. Many lines of evidence indicate that their behavioral capacities are sufficiently complex to enable them to form associations of the order of complexity needed here. The answer seems to lie partly in the lack of crucial tests for the presence of addiction and, more importantly, in the fact that they have ordinarily been caught and injected by force in such experiments. Careful pre-morphinism training of the animals in coöperation and voluntary submission to injection procedures might have resulted in a much different picture.

Although the chimpanzee is thus seen to be at present the most valuable animal available for experimental studies of morphine administration, it must be admitted that there are certain factors contraindicating its extensive use in problems of this sort. Chief

among these are expensiveness and relative non-availability of subjects, as well as the expense of equipment needed for their caging and use. For these reasons chimpanzee studies in this field must necessarily be studies with small numbers of subjects. It seems clear, therefore, that the chimpanzee, although clearly the most valuable and promising animal available for addiction studies, will never be widely used in such investigations.

However, the use of chimpanzees in the present experiments seems to indicate rather clearly ways in which various types of monkey might be used in research in this field with considerably more behavioral success than has been the case so far. It is the writer's belief that if a relatively tractable monkey, such as the mangabey (Cercocebus) for example, be given the training and experimental procedures which were used in the present investigation, the chances of developing a genuine addiction to morphine would be very good.

If such should prove to be the case, it would be of considerable practical importance for research in fundamental problems in drug addiction. It would mean that investigations in this field could be carried out in a great many laboratories (instead of a very few, as with chimpanzees), and that relatively large numbers of animals could be employed as subjects. This would make feasible various statistical comparisons, as well as the investigation of problems requiring the experimental sacrifice of several subjects, without excessive expense.

B. SUMMARY

1. The present experiment has attempted (a) to determine as much about the effects of morphine and the nature of chronic morphinism in chimpanzee as was feasible under the conditions obtaining, with emphasis upon behavioral aspects, and (b) to determine whether or not chimpanzees develop a genuine addiction to morphine.

2. The effects of small, isolated doses of morphine on young chimpanzees were studied in 35 cases, and found to be comparable in many ways to those reported for man and for monkey.

3. Chronic morphinism was induced in 4 young chimpanzees

(3 males and 1 female), the duration of drug administration being: 13 months, 7 months, 4 months, and 6 weeks. The dosage was maintained at 2 to 3 milligrams per kilogram of body weight, twice daily.

4. Administration of the drug was found to affect several physiological and behavioral functions, as determined by comparison with pre-morphine measurements.

5. Behavioral evidences of a definite, strong desire for the morphine injection appeared in 3 of the 4 subjects (the exception being the animal that received morphine for only 6 weeks). Two of the subjects were tested in an experimental situation designed to determine objectively whether desire for the injection was present; both exhibited unequivocally the existence of a genuine addiction.

6. For the male chimpanzee, morphine doses were found to stimulate sexual functions (erections, auto-erotic behavior, eagerness to copulate), while withdrawal acted as a depressant; these results are in contrast with those reported for human addicts and for morphinized monkeys. Morphinism inhibited genital swellings and probably delayed the appearance of first menstruation in the female subject.

7. Morphine withdrawal was studied by means of a series of partial, and 2 complete, withdrawals from the drug. The symptoms resembled in many ways those reported for human addicts, behaviorally as well as physiologically.

8. A discussion of the nature of morphine addiction in chimpanzee and man was undertaken, and the thesis was defended that morphine addiction is fundamentally a physiogenic phenomenon, developed according to principles of association. That the "societal" factor (which is usually present in human addictions) is not essential in the development of addiction has been demonstrated by the present results.

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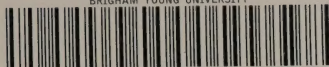
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